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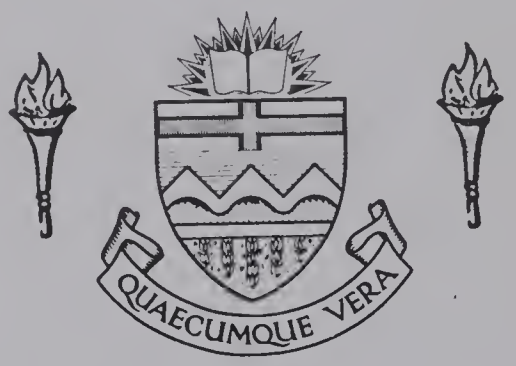

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TEACHING FOR PROCESS IN SCIENTIFIC INQUIRY

by

© DAVID POWLEY

A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Teaching for Process in Scientific Inquiry" submitted by David Powley in partial fulfilment of the requirements for the degree of Master of Education.

ABSTRACT

This developmental study is concerned with the question: "How to teach for the process of science?" A methodology is proposed in terms of instructional strategies which may be used in teaching for process in scientific inquiry as outlined in "An Inventory of Processes in Scientific Inquiry". The inventory consists of five major processes: (I) Initiation, (II) Collection of Data, (III) Conceptualization of Data, (IV) Processing of Data, and (V) Open-endedness.

The design of the study is structured in terms of an instructional model consisting of: Phase I, the stating of objectives in behavioral terms; Phase II, the structuring of appropriate learning experiences based on the stated objectives; Phase III, the evaluation of the objectives and, Phase IV, analysis and revision.

Instructional modes based on statement of behavioral objectives in the process domain were used to develop this dimension. The instructional modes for which strategies are provided are: laboratory, field studies, demonstrations, history of science, A-V media, invitations to inquiry, simulation, project, and lecture and discussion. The basic premise in the development of the strategies is the involvement of the student in lessons representative of a scientist and the scientific enterprise.

Five teachers participated in the study. Reports of classroom procedures were obtained and analyzed, in order to ascertain the nature of their classroom activities. An Observational Instrument was developed to assess the reliability of the teacher reporting and their interpretation of the process inventory. It was

found that each teacher was unique in his approach to process teaching. Misconceptions in interpreting the processes were noted when compared to a criterion as developed by the researcher and a colleague. The teachers employed the laboratory, A-V media, lecture and discussion as the major instructional modes. The processes that were stressed were: identification and formulation of the problem, hypothesis, design for collection of data, procedure, observations and observing, and interpreting data. The impression that the teacher did not fully comprehend the syntactical aspects of science appeared to be supported.

The findings suggest four generalizations:

1. In the development of a science curriculum and teaching of this curriculum, teachers should have a model for instruction to guide their activities.

2. Teachers of science should have a clear understanding of scientists, the scientific enterprise , and the aims and methods of scientists, and should display behaviors that are characteristic of scientists.

3. Teachers should attempt to provide science instruction in the processes through a variety of instructional modes.

4. Opportunities should be provided for as many processes as possible to be developed so as to involve the students cognitively and practically in the processes of science .

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CHAPTER I

THE NATURE AND SIGNIFICANCE OF THE PROBLEM

I. INTRODUCTION

The present science is an evolutionary process that consists of concepts and relationships that mankind has abstracted from observations of natural phenomena over the centuries. This has provided a structure to science that is dynamic and emergent. Within this enterprise developed processes and methods of inquiry. As stated by Obourn:

> Science is a subtle thing: It is part product and part process, part control and part understanding. And these two entities are bound inextricably together in the true image of science.[1]

The result is a conceptual structure of science and a point of view with which a scientist approaches his work.

It is being conceived that the value of school science content does not lie so much in its accumulated information or in its artifacts in the different disciplines but in its special way at looking at phenomena, in its methods of inquiry, its procedures for utilizing research, and its models for systematic thought. This changing aspect is summarized by Schwab as he states:

> With the disappearance of the self-evident giveness of fixed dimensions and the traditional properties of time, space and motion, self-evidentness itself is disappearing. For the purposes of science, facts can no longer be

---

[1]Ellsworth S. Obourn, "Science as a Way of Life," Readings in Science for the Elementary School, Ed. Edward Victor and Majorie S. Lerner (New York: MacMillan, 1967), p. 3.

> treated as self-existing givens. They are matters contingent on the knower: on the operations he performs to bring them into view and on the conceptions which organize and control his operations.[2]

A problem in teaching science is to take the product and the content of science, and to approach this study by inquiring how a scientist gives meaning to a concept in such a way that its relevance to the study of the natural phenomena is assured. In a publication, the National Science Teachers Association (NSTA) has defined science as:

> . . . activity and as content, as process and product. The product owes its existence to the process: on the other hand, the process is impossible and pointless without the product, the knowledge of science.[3]

Thus, it could be argued that process is dictated by the problems of the scientific enterprise. The importance of this aspect of science has been summed up in the following words:

> The behavior of people is marked by the process of science. It influences the extent to which they are self-directing and self-reliant - and the extent to which they seek and arrive at rational decisions to issues and effective solutions to problems. This science-influence behavior applies to society and also to individuals. While not necessarily being creative in the more profound sense, all individuals can profit by using the methods and attitudes of science in finding needed information and seeking solutions to life's multitude of problems. In this sense, every

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[2] J.J. Schwab, "The Teaching of Science as Enquiry," The Teaching of Science (Cambridge: Harvard University Press, 1962), pp. 11 - 12

[3] National Science Teachers Association, Planning for Excellence in High School Science (Washington: The National Education Association, 1961,), p. 15.

man could be his own scientist - his own problem solver.[4]

It can be surmised that as this new and pervasive culture goes forward, it is essential that the students in our schools be trained in the process of science along with its product. Process goals have to some extent been analyzed into elements in much the same manner as concepts in the content areas. What is essential is classroom research to develop expert methods for teaching the process of science.

II. STATEMENT OF THE PROBLEM

This is a developmental study concerned with the question: "How to teach for the process of science?" It attempts to propose a methodology in terms of instructional strategies that may be used in teaching for process in scientific inquiry. Specifically, the study involved the processes as outlined in "An Inventory of Processes in Scientific Inquiry."[5] A number of instructional modes are used in an attempt to develop learning experiences in the process domain.

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[4] _____ "Planning for Quality High School Science" (Committee Report), in Victor, op. cit., pp. 6-7.

[5] M.A. Nay, et al., "Inventory of Processes of Scientific Inquiry." (Alberta: Edmonton) Unpublished paper prepared by the Edmonton Junior High School Project, 1968. (Mimeographed). See appendix for a revised outline as submitted to Science Education.

III. THE PURPOSE OF THE STUDY

As is mentioned in the introductory statements, the need for developing understanding and proficiency in the process dimension of science is recognized. The Curriculum Guide for Junior High School Science for Alberta under the topic "Skills to be Developed in Science" - Process Skills states:

> A key objective of the junior high school science program is to make the student an increasingly active and dynamic investigator of science - using the processes of the scientist. Through conscious, systematic development of these processes, the student becomes increasingly better equipped for more complex learning in the fields of science as well as in other areas of investigation.[6]

From the departmental statement it was inferred that the processes of science are to have a beneficial effect for students of science. The guide lists the desired processes, but very little is provided as to a suggestive methodology for teaching them or for incorporating them into the scientific enterprise as it is reflected in science teaching.

Therefore, the investigator took the "An Inventory of Processes of Scientific Inquiry", a behaviorally directed structure of processes involved in the scientific enterprise, and with the prevailing philosophy for science education, attempted to develop a methodology that will provide a basis for teaching for the process of science.

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[6]Department of Education, Province of Alberta, Curriculum Guide for Junior High School Science. (Edmonton: Queen's Printer, 1969). p. 2.

IV. DEFINITION OF TERMS

To clarify aspects of this study the following definitions are held:

Process refers to a behavioral description of the various procedures that scientists appear to carry out in their pursuit of understanding nature; i.e. defining problems, hypothesizing, analyzing data, etc. This includes those procedures as defined in "An Inventory of Processes in Scientific Inquiry." These behavioral aspects are within the cognitive domain (the intellectual abilities and skills of the scientific enterprise) and the psychomotor domain (manipulative skills). These procedures are affected by aspects of the affective domain of the individual (his emotions, attitudes, appreciations or values).

Inquiry refers to the cognitive and affective behavior exemplified by the use of the processes. Essentially, it is a form of learning which involves an awareness of the ways in which scientific knowledge has been developed along with increased skill in the use of the processes of scientists.

Strategy refers to the plan for achieving the goal of learning. It does not imply a victory for the teacher and a defeat for the pupil. The teacher and pupil are to be viewed as cooperating in a plan that benefits both of them but primarily the student. "In the sense that a teaching strategy is a plan to attain certain goals and to guard against undesirable result, the concept of strategy is meaningful to teaching."[7]

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[7] Ronald T. Hyman (ed.), Teaching: Vantage Points for Study (New York: J. B. Lippincott Co., 1968), p. 139.

Instructional Mode refers to the method or form that is employed in inquiry to develop the process(es).

An Inventory of Processes in Scientific Inquiry refers to the processes which are generally observed when scientists are at work as developed by the Edmonton Junior High Science Project. (see appendix A)

The Observational Instrument refers to the structured format developed for gathering information on the science processes taught and the characteristics of the science teaching in the classroom. (see appendix C)

V. DELIMITATIONS OF THE STUDY

General

This study takes an "applied research" format as opposed to "basic" or pure research. It is generally a descriptive study as well as being developmental in nature. The descriptive aspect attempts to describe science processes as taught by selected teachers: the developmental aspect attempts to develop instructional techniques and products that have immediate classroom use. Using "laboratory classrooms" the main purpose was to engineer specific products which could later be tested more vigorously when used under ordinary classroom conditions.

Specific

1. This research does not incorporate into the design of the teaching strategies the acquisition of attitudes of a scientist (affective domain) by the pupil, and how these may be applied to his daily living. If this dimension was brought in,

it was of an incidental nature.

2. This research does not evaluate the effectiveness of the methods and approaches proposed in the development of a methodology of teaching for processes. The contention is that this is a part of science teaching that needs development, and that one must first develop the theoretical structures. Furthermore, instruments need to be devised or refined to measure the "process" dimension in scientific inquiry.

3. The research took cognizance of the fact that any development of a methodology for instruction and teaching must recognize the developments of learning theories in psychology. The developmental aspects were based on an eclectic set of beliefs. The contention is that this research itself is proposing a theory of instruction which in time, through application and testing will demonstrate its value. It is also accepted that each teacher needs to build a theory into his own permanent position and show how his ideas fit and control the learning situation of his pupils. As a result, the developments in this study were not considered in terms of or result of their psychological implications.

4. The study was conducted at the junior high school level.

5. The educative process being what it is, the developmental aspects considered the child (the student) as of prime importance and his teachers as attempting to provide the most satisfactory educative interaction during the study.

VI. LIMITATIONS OF THE STUDY

1. The data that is presented is subject to the limitations that are due to

teacher experience, bias, and perceptions of self-evaluations.

2. It was assumed that the "An Inventory of the Processes of Scientific Inquiry" contained and implied the process skills that are employed by practicing scientists.

VII. SIGNIFICANCE OF THE STUDY

Before one is able to appreciate the contribution and implications of this study to science education, the assumptions held and the position of the researcher needs to be elaborated since it was in the presence of these views that the methodology was developed.

In the development of this methodology for teaching for process through inquiry, the students must see a link between their own lives and science if they are to gain experience from science. This view is well summarized by Butts who states:

> Because experience is a prerequisite to development of both knowledge and skills, the structure of that experience becomes a significant factor in science instruction. Students must feel they are studying something of value and not merely executing intellectual minuets. They must actively do something with material, carrying out their own action and then have reason and time to stop and examine the results of their action. This means designing curriculum materials in which the student's experience is a personal thing, stimulated from direct observation of an event. This experience leads to inference about relationships and to the testing of these inferences. This design contrasts sharply with the situation in which a student solves a puzzle that has been imposed on him by the teacher, the solution of which has for its main reward the completion of an external requirement. Only when given the opportunity to struggle with conditions of an event first hand and to seek and find his way out will a student experience both relevance and self-

directed responsibility.[8]

Second, it was also the view that in teaching for process that the teacher direct his efforts toward indentifying the large principles and generalizations, the conceptual structures (in content) which undergird a discipline. It is here that one can concur with Schwab:

> There is still need and vital need for a minimum education which consists of useful bits and pieces of the content of the disciplines. But the best possible selection of the most useful of bits and pieces from the disciplines would constitute, today only one portion of the curriculum we need. Other and more profound changes in the scientific disciplines now make it urgently desirable that we teach something more than their content, their conclusions, selected or unselected. These other and more profound changes make it urgently desirable, indeed, that somewhere and somehow within the school curriculum we also convey a sense of the structures of the disciplines. For, as we shall see, without some understanding of these structures, the learning of conclusions of content, becomes mislearning and misunderstanding.[9]

This view contrasts strongly with that taken by AAAS - A Process Approach, where the processes themselves are the main content objectives with the subject material from all disciplines being implemented to suit the process objective.

It was also the view in this development that to genuinely possess knowledge, and to be able to put it to its most profitable advantage, the learner must be given an opportunity to discover (investigate) this knowledge through an

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[8]David P. Butts, "Opening the World to the Student," Designs for Progress in Science Education, The National Science Teachers Association (D.C., Washington, 1969), p. 32.

[9]Joseph J. Schwab, "The Concept of Structure in Subject Fields," paper presented at the 20th Annual Meeting, Council on Cooperation in Teacher Education, Washington, D.C., 1961, cited in Process as Content, Ed. J. Cecil Parker and Louis J. Rubin (Chicago: Rand McNally, 1966), p. 8.

active process of inquiry. This view is supported by some of the hypotheses advanced by Bruner who stated:

> . . . that it is only through the exercise of problem solving and the effort of discovery that one learns the working heuristic of discovery, and the more one has practice, the more likely is one to generalize what one has learned into a style of problem solving or inquiry that serves for any kind of task one may encounter - or almost any kind of task.[10]

Such an approach makes it possible for the student to be actively involved in the process of science rather than just having a cognition of it, and also provides excellent opportunities for the affective and psychomotor domain developments. To incorporate this investigative aspect of inquiry, the "An Inventory of Processes in Scientific Inquiry" was used in the development of the teaching strategies which consciously make the student take responsibility for his own learning.

The fourth major concern in this development of teaching for process was that the learner function in the manner of the scholar within the operational peculiarities of a given discipline and that part of the students' activities be a classroom emulation of the professional's procedure. Both Bruner [11] and Brandwein subscribe to this view. Brandwein states:

> In the scientist's way of life is a process: enquiry. It embodies an aim: the construction and dissemination of a meaningful world. In it is

---

[10] Jerome S. Bruner, "The Act of Discovery," Studying Teaching, ed. James Raths, et al., (New Jersey: Prentice-Hall, Inc., 1967), pp. 214-215.

[11] Jerome S. Bruner, The Process of Education (Cambridge: Harvard University Press, 1960) p. 60.

> a posture: individual liberty, or idiosyncracy, in mode and method of investigation. In this way of life is a kind of humility: there is a mistrust at one's brain to reach grand conclusions; hence a self-correcting attempt to defeat one's own conclusions; there is also the knowledge that the only certainty is uncertainty. The way of a scientist, we repeat, is not to be interpreted as a calisthenics of discovery but an art of investigation. In the long run the scientist knows a kind of success, but it comes from intelligent failure.[12]

These latter two aspects have considerable implications for developing a teaching strategy. As mentioned by Nay and Crocker[13], this is the "imitative approach" that may be used as a teaching strategy. This strategy is not only a method of teaching affective attributes of scientists but, is also most appropriate in implementing "process".

Therefore, in the light of the researcher's viewpoints, the purpose of this study is to propose a methodology for science teachers that will include strategies developed to teach for process in scientific inquiry. It is hoped that some answers and tentative developments are proposed to the questions posed by Mokosch and others as they stated:

> . . . regarding ways and means of teaching for the processes in scientific inquiry.[14]

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[12]Paul F. Brandwein, "Elements in a Strategy for Teaching Science in the Elementary School," The Teaching of Science, ed. Joseph J. Schwab and Paul F. Brandwein (Cambridge: Harvard University Press, 1962) pp. 112-113.

[13]M.A.Nay and Robert K. Crocker, "Science Teaching and the Affective Attributes of Scientists," Science Education, LIV (Jan.- Mar., 1970), p. 65.

[14]Eric Mokosch, "The Development and Evaluation of a Process Approach to the Teaching of Junior High School Science" (unpublished Doctoral dissertation, University of Alberta, 1969), p. 105.

> . . . far too little is known about how to teach certain processes. . . . Action research to try various means and techniques will have to be attempted.[15]

> And, of the greatest moment, is the need for a systematic exploration of the ways in which process and content can be fused into an effective program of instruction.[16]

It is hoped that this study will be of benefit to the science teachers of this province and to programs being developed by the Edmonton Junior High School Research Project - "A Process Approach."

VIII. THESIS OVERVIEW

In this chapter the problem, purpose, and significance of the study was established. The next chapter presents a review of the literature; in which the process dimension, inquiry, and teaching for process are explored. Chapter III consists of the design of the study. The chapter following presents the development of modes for process approach teaching. A description, analysis, and interpretation of process approach teaching by five teachers is summarized in Chapter V. The concluding chapter presents a summary of the complete study, conclusions, implications and suggests problems for further research.

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[15] Ibid., p. 112.

[16] Cecil Parker and Louis J. Rubin, Process as Content: Curriculum Design and the Application of Knowledge (Chicago: Rand McNally & Co., 1966), p. 66.

CHAPTER II

A REVIEW OF THE LITERATURE

I. INTRODUCTION

In order to facilitate the review of literature relevant to the problem under consideration, this chapter is divided into three sections. The first section provides a rationale and theoretical support to the process domain in science teaching, the second section relates this to the aspect of scientific inquiry and the final section reviews some of the major attempts at teaching for process in science.

II. THE PROCESS DOMAIN IN SCIENCE TEACHING

Science educators have realized the process features as an objective of science teaching for some time. The "scientific method" or "problem-solving" of the past is related to the present process approach. Each of these is concerned with situational features where problems are identified, previous knowledge is considered, hypotheses are proposed and tested, and an explanation to the phenomena provided.

To express the goals in operational terms educators have relied heavily on interpretations of Dewey (1933). The concept he postulated as the scientific method was a series of steps: (1) definition of the problem, (2) collection of data, (3) formulation of a hypothesis, (4) testing of the hypothesis, (5) drawing a

conclusion, and (6) applying the conclusion.[1]

This formalism was used in science teaching for a number of decades but modification began to appear since the specific steps presented an inadequate description of what scientists do.

Reflecting this movement, Keeslar analyzed the elements of the scientific method and concluded the following:

> The elements of scientific method are definite, distinct from scientific attitudes, and known and used by scientists.[2]

Thus it could be claimed that there are elements that can be distinguished in the scientific enterprise. But Keeslar recognized a problem perplexing this whole study -- one which is much apparent today:

> It seems justifiable to assume, therefore, that as soon as effective methods and means of teaching the elements of the scientific method and the scientific attitudes are found, the high-school students' chances of success in meeting and solving everyday problems will be greatly enhanced, . . .[3]

This stress on problem solving was reinforced by the forty-sixth NSSE yearbook (National Society for the Study of Education, 1947), which advanced the following objectives that could be interpreted in relation to the processes

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[1]American Education Research Association, Encyclopedia of Educational Research, ed. Robert I. Ebel, (fourth ed., London: Collier-MacMillan Ltd., 1969), p. 1193.

[2]Oreon Keeslar, "The Elements of Scientific Method," Science Education, XXIX (Dec. 1945) p. 277.

[3]Ibid., p. 277.

of scientific inquiry:

E. Problem-solving skills, such as ability to:

1. Sense a problem
2. Define a problem
3. Study the situation for all facts and clues bearing upon the problem.
4. Make the best tentative explanations of hypothesis.
5. Select the most likely hypothesis.
6. Test the hypothesis by experimental or other means.
7. Accept tentatively, or reject the hypothesis and test other hypothesis.
8. Draw conclusions.[4]

To compliment this list, objectives in Instrumental skills, Attitudes, Appreciations, and Interests were also outlined. It would seem that here was recognition of aspects of a process dimension to the scientific enterprise, but somehow the "product" played a larger role and the behavioral aspects of process were left dormant in the teaching of science.

The issue in time is again raised by Obourn. Believing that problem-solving behavior in science is a complex ability made up of elements which can be identified, and that these are essential to suggest guides for teachers in planning classroom situations and in evaluation, Obourn analyzed problem solving behaviors into eighty or so skills. Having overtones of previous works, (Dewey,

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[4]National Society for the Study of Education, Science Education in American Schools, Forty-Sixth Yearbook, Part I. (Chicago: University of Chicago Press, 1947), p. 29.

Keeslar, NSSE) his general categories were:

A. Formulates significant problems.
B. Analyzes problems.
C. Obtains information regarding a problem from a variety of sources.
D. Organizes the data obtained.
E. Interprets organized data.
F. Tests the hypotheses.
G. Formulates a conclusion.[5]

It is interesting to note that the objectives are well stated, but hardly any proposals or attempts are made in methods of transforming these to classroom situations. Then in 1960, the NSSE, in its fifty-ninth yearbook proposed some guidelines for teaching for the purposes of scientific inquiry although these were very much teacher objectives. On problem solving they maintained:

> Science is a process in which observations and their interpretations are used to develop new concepts, to extend our understanding of the world, to suggest new areas for exploration, and to provide some predictions about the future. It is focused upon inquiry and subsequent action.
>
> Methods for solving problems in science are numerous. There is no one scientific method ... What is done is highly flexible and quite personal... The methods of science are something more than measurements, laboratory techniques... Sometimes they are not very logical, but search for truth is always present. Presenting problem-solving as a series of logically ordered steps is simply a technique to isolate the critical skills and abilities and to give them special attention in teaching.
>
> A process of inquiry involves careful observing, seeking the most reliable data, and then using rational processes to give order to the data

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[5]Ellsworth S. Obourn, "An Analysis and Check List on the Problem Solving Objectives", Science Education, XL (Dec., 1956), pp. 338-392.

and to suggest possible conclusions or further research. . . [6]

This acknowledges the fact that problem-solving is a process and that it is also a form of inquiry. Accordingly, numerous educators started approaching science from a different point of view. Heathers, suggests that science (elementary) be process-centered. He proposes three categories: (1) the process of inquiry, commonly called the scientific method; (2) processes in nature, discovered through using the scientific method - the cause and effect relationships; and (3) process of applying knowledge - the technological aspects of science. [7]

But as with people before him, Heathers does not propose ways of developing these in the classroom situation.

As a result of these objectives and further expositions by Watson, Butts and the NSTA (National Science Teachers Assocation) the sixties advanced with the "processes of science" objective commencing to be strongly accepted.

One of the first real attempts at process teaching is the program Science - A Process Approach. The basic premises of Science - A Process Approach, are stated by Gagne as follows:

> 1. The scientist's behavior in pursuing science constitute a highly complex set of intellectual activities which are, however, analyzable into simpler activities.

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[6] National Society for the Study of Education, Rethinking Science Education, Part 1 (Chicago: University of Chicago Press, 1960), p. 35.

[7] Glen Heathers, A Process-Centered Elementary Science Sequence, Science Education, XIV (April, 1961), pp. 201-206.

2. These intellectual activities (processes) are, as most scientists would agree, highly generalizable across scientific disciplines . . . .

3. These intellectual activities of scientists may be learned, and it is reasonable to begin with the simplest ones, and build the more complex activities out of these, since this seems to be in fact the way they are organized.

4. Accordingly, one can construct a reasonable sequence of instruction which aims to have children acquire process skills, beginning with simple kinds of observation, and building progressively through classifying, measuring, communicating, quantifying, organizing through space and time, to the making of inferences and prediction. As further building occurs, one finds it possible for students to learn how to make operational definitions, how to formulate testable hypotheses, how to carry out experiments, and how to interpret data from experiments. . . .

5. At the end of such instruction, the student will not necessarily know anything which can be identified as physics, or chemistry, or biology, or geology. What will he know then? Perhaps something like this: A scientist should be able to tell this student what he (the scientist) is studying and the techniques he is using, and what he has found, in a relatively brief fashion, and have the student display a rather profound understanding of it immediately. . . .[8]

On the basis of these psychological considerations, Science - A Process Approach, recognizes the following processes:

The Basic Process

Observing
Using Space/Time Relationships
Classifying
Using Numbers
Measuring
Communicating
Predicting
Inferring

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[8]R.M. Gagné, "Psychological Issues in Science - A Process Approach", The Psychological Basis of Science - A Process Approach, Commission on on Science Education. (Washington: The American Assoc. for the Advancement of Science, 1966), p. 4.

The Integrated Processes

Formulating Hypotheses
Defining Operationally
Controlling Variables
Interpreting Data
Experimenting [9]

It is difficult to find any criteria for the processes chosen, but many of them have appeared on similar lists in the past. The significant aspect of this approach is that a form of an instructional program was developed which makes the processes of science a behavioral objective to be attained. A teaching strategy based on a psychological plan was also developed.

In India, Brown with a group of educators has defined in operational terms the objective "to teach the processes of science." The various facets of this objective have been arranged in a hierarchy which conforms somewhat to the Taxonomy of Educational Objectives by Bloom, et al.[10] Though not to be accepted as sequential, the major elements of this list are:

A. Application of Generalizations to New Situations
B. Collections of Data
C. Analysis of Data
D. Synthesis of Data
E. Evaluation of Data[11]

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[9] American Association for the Advancement of Science, Science - A Process Approach - Commentary for Teachers, (3rd ed.) (Washington: the Association, 1968)

[10] Benjamin S. Bloom, et al., Taxonomy of Educational Objectives: Cognitive Domain (New York: David McKay Company, Inc., 1956).

[11] Walter B. Brown, "Defining the Processes of Science," The Science Teacher, XXXV (Dec. 1968), pp. 26-28.

This group is also concerned with the development of lesson plans and instructional materials and the development of methods to evaluate pupil growth in the understanding and use of the processes of science.

In developing an instrument for inventorying knowledge of the processes of science Welch describes the processes of science as:

> Scientific process is described as a series of activities or operations performed by the scientist in his attempt to understand nature. These activities are based on various assumptions and are guided by an awareness of the nature of the outcomes and the ethics and goals of the discipline.[12]

On the basis of literature research and validation by a panel of scientists, he assumed the following outline to be a valid description of the processes of science:

Elements of Scientific Processes

I. Assumptions

- A. Reality
- B. Intelligibility
- C. Consistency
- D. Causality

II. Activities

- A. Observation
  1. Selected
  2. Influenced by past experience
  3. Using instruments
  4. Recording
  5. Describing accurately
  6. Unexpected

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[12] Wayne Willard Welch, "The Development of an Instrument for Inventorying Knowledge of the Processes of Science" (unpublished Doctor's Dissertation,

B. Measurement
C. Classification
D. Experimentation
E. Communication
F. Mental Processes
   1. Induction
   2. Formulate Hypotheses
   3. Deduction
   4. Formulate Theories - prediction
   5. Multiplicity of techniques and procedures

III. Nature of the products (outcomes)

A. Probability
B. Tentativeness
C. Theories
D. Models
E. Laws

IV. Ethics and goals

A. Goals and motivation
B. Objectivity
C. Anti-authoritarianism, skepticism
D. Amorality
E. Repeatability
F. Parsimony[13]

This list incorporates many of the processes found in the previous ones but is more inclusive in that it concerns itself with the nature of science (i.e. what science is and its philosophy) and with the affective attributes of scientists as well as the processes. All three are common to all scientific inquiry and critical to scientific thought. Although, this inventory was intended to serve an

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U of Wisconsin, 1966), University Microfilms Ltd., Ann Arbor, Michigan.

[13] Ibid., p. 33.

evaluative objective, it does provide insights into what may take place in a science curriculum. If the inventory is accepted as being representative of the science processes as used by practicing scientists, then it is reasonable to believe that evaluative objectives can become aims and objectives to be achieved. It would follow that teaching methods and the learning of science would then be approached along this dimension.

In 1967 in a cooperative effort of classroom teachers and university personnel under the direction of M.A. Nay, a group set out to determine a theoretical framework upon which a science curriculum recognizing the importance of the process dimension could be built. As noted, many descriptions of what scientists do are available. However, there was a need for improved and new approaches to describing the behavior of scientists and for reflecting this dimension in the teaching of science.

Using the inventory approach, the following framework entitled "An Inventory of Processes in Scientific Inquiry"[14] was developed.

I. Initiation

1. Identifying and formulating a problem
2. Seeking relevant background information
3. Predicting
4. Hypothesizing
5. Design for collection of data through field work and for experimentation

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[14] This inventory is based on the 1970 manuscript, "A Process Approach to Teaching Science," by M.A. Nay and Associates, submitted to Science Education.

II. Collection of Data

6. Procedure
7. Observing and observations

III. Processing of Data

8. Organizing the data
9. Representing the data graphically
10. Treating the data mathematically

IV. Conceptualization of Data

11. Interpreting the data
12. Formulating operational definitions
13. Expressing data in the form of a mathematical relationship
14. Incorporating the new discovery into existing theory

V. Open-endedness

15. Seeking further evidence
16. Identifying new problems for investigation
17. Applying the discovered knowledge

This inventory, is further divided into sub-categories and each process has been described in some detail, being delineated as to its purpose in scientific inquiry and its relationship to other processes.*

It should be recognized thatthis inventory does not include the nature of science (i.e. Welch) or specific processes, such as communication or creativity (i.e. AAAS). These facets are believed to be overriding processes applicable in all aspects of scientific endeavor. At the same time this inventory is a more complete listing of the processes that are involved in scientific inquiry in

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* See Appendix A

comparison to the development put forth by the AAAS or Welch.

The processes are stated in an active tense to impart to them the character of general behavioral objectives. In order to serve as a guide for programming, instruction, and evaluation, they need to be made specific in the science lesson.

Another facet of this inventory, is that it includes in the formalism not only processes of scientific inquiry but also an approach to education. In its gross structure, i.e. Initiation, Collection of Data, Processing of Data, etc., a natural structure to teaching emerges. As a result, this inventory can serve as a guide and stimulus for teachers to pay attention to this dimension in a more conscious and continual manner.

Within this inventory opportunities for self-learning and independence are most favorable. By withdrawing instructions to the processes and requiring students to select needed processes and to work out the specifics of their application for the investigation being pursued, students become involved in the scientific enterprise. As the student gains experience, the inventory makes it possible for him to implement it independently in solving any given problem. It is this inventory that was used in the development of the teaching strategies in this study.

With the processes of science spelled out in the form of objectives, it is hard to imagine why the explicit teaching for this dimension has become a major objective of science teaching only recently. The reason could be attributed to the fact that "inquiry" or "scientific inquiry" was also an idea that took time to develop.

III. SCIENTIFIC INQUIRY

Although it is similar to discovery in concept, inquiry suggests a somewhat different emphasis, with greater stress on the processes by which discovery proceeds.[15] Could it be that the teaching for process in science required a method or manner of doing in science teaching?

With attention being directed to an inquiry approach to teaching, inquiry processes became matters of concern. In the teaching the inquiry processes it was noted that the teaching of concept was inseparable from process. As a result through an interest for inquiry teaching, the process elements became focal components in the overall instruction in science.

One of the leading proponents of inquiry teaching in science, Schwab states the following:

> To teach science as enquiry means, first, to show students how knowledge arises from the interpretation of data. It means second, to show students that the interpretation of data -- indeed, even the search for data -- proceeds on the basis of concepts and assumptions that change as our knowledge grows. It means, third, to show students that because these principles and concepts change, knowledge changes too. It means, fourth, to show students that, though knowledge changes, it changes for good reason -- because we know better and more than we knew before.[16]

In this expression, Schwab tells us what inquiry is and presents us with

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[15] C. K. Brown, "Pupil Personality and Teaching Style" (unpublished Doctoral Dissertation) (Edmonton: University of Alberta, 1967), p. 27.

[16] J. J. Schwab, "Invitations to Enquiry," Biology Teachers Handbook (New York: John Wiley and Sons, Inc., 1963), p. 46.

its goal. He then takes the methods of science (process) and develops an approach to methodology.

Within his framework, Schwab enunciates many practical aspects, but what he implies is clarified when he states:

> Such a completely enquiring classroom requires teaching and learning skills which are not the common habit of our schools. Its aim is not only the clarification and inculcation of a body of knowledge but the encouragement and guidance of a process of discovery on the part of the student.
>
> For the student, this means relinquishing of habits of passivity, docile learning, and dependence on teacher and textbook, in favor of an active learning in which lecture and text book are challenged. The lecture and textbook cease to be authoritative sources of information to be learned and become materials to be dissected, analyzed. For, in one form or another, the materials of such a classroom are not statements of truth but reports of enquiry. Hence, the students' attention is not something said but something done. The oral and written material presented him still, inevitably, are sayings. But the student's attention is not upon the statements as statements - words and assertions to be learned - but on what the words and assertions are about: the thoughts and the actions of a scientist which have gone into the making of a piece of scientific research.[17]

Thus there is an established need to structure knowledge to fit the inquiry aspect of the classroom. With impetus provided by Bruner, using the nature of science as his body of knowledge, Schwab postulates that the structure of any given discipline, such as science, consists of the substantive aspects (product or content) and the syntactical (process of inquiry) aspects.[18] This has had the

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[17] Joseph J. Schwab, "The Teaching of Science as Enquiry," The Teaching of Science, Joseph J. Schwab and Paul F. Brandwein (Cambridge, Mass: Harvard University Press, 1962), pp. 65-66.

[18] _____, "The Structures of the Disciplines: Meanings and Significances," The Structures of Knowledge and the Curriculum, ed. G.W. Ford and L. Pugno (Chicago: Rand McNally and Co., 1964).

effect of educators asking for a "framework of processes" to get at the syntactical structure. The content aspect of science is well developed. It was at this juncture that attempts to teach for processes in scientific inquiry began to be developed with some rationale.

The impact of this philosophy soon had many implications. In teaching science as inquiry, Tyler expresses:

> It must become a process in knowing how to raise questions which are relevant to science and how to carry on investigations of these questions: it must include investigations which keep broadening and deepening the student's understanding of the questions themselves and also considerations that need to be taken into account and finally the adequacy and incompleteness of possible answers.
>
> To teach science in these terms requires a change in notion of what has to be covered, a change in the kinds of learning experiences provided, a change in instructional materials used, a change in the tests, examinations, and other evaluation procedures.[19]

It was only a matter of time after this approach was discussed that certain people started linking these ideas with science content and learning theories. One of the first of these was Gagné, who proposed a process curriculum based heavily on his learning theory.[20] From this came the development of Science - A Process Approach. Gagné provides the following rationale for the "process

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[19] Ralph W. Tyler, "Forces Redirecting Science Teaching," The Science Teacher, XXIX (Oct., 1962), pp. 22-25.

[20] Robert M. Gagné, "The Learning Requirements for Enquiry," Journal of Research in Science Teaching, (March, 1963), pp. 144-153.

approach":

> This approach seeks a middle ground between the extremes I have mentioned. [the "content" approach and the "creativity view". . .] Specifically, it rejects the "content approach" idea of learning highly specific facts or principles. . . It substitutes the notion of having children learn generalizable process skills which are behaviorally specific, but which carry the promise of broad transferability across many subject matters... The point of view is that if transferable intellectual processes are to be developed in the child for application to continued learning in the sciences, these intellectual skills must be separately identified, and learned, and otherwise nurtured in a highly systematic manner. [21]

Although this program was designed for the elementary level, it was a major effort in that it placed the emphasis completely on "process" of science in an inquiry framework. As for studies in inquiry teaching, Scandura,[22] Ivany,[23] Scott,[24] Suchman[25] and Brown[26] have all added specific aspects to the inquiry method but have provided very little for the process dimension. Most

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21 _____, "The Psychological Bases of Science - A Process Approach," American Association for the Advancement of Science, (AAAS Miscellaneous Publication, 1965), p. 4.

22 Joseph Scandura, "An Analysis of Exposition and Discovery Modes of Problem Solving," Journal of Experimental Education, XXXIII (Winter, 1964) pp. 149-159.

23 G.W. Ivany, A Comparison of Expository and Hypothetical Modes of Teaching Science (Unpublished Doctoral Dissertation, Edmonton: University of Alberta, 1965).

24 N.C. Scott, "The Strategy of Inquiry and Styles of Categorization," Journal of Research in Science Teaching, IV (Sept., 1966) pp. 143-153.

25 Richard J. Suchman, "The Illinois Studies in Inquiry Training," ed. James Raths, et al. Studying Teaching (New Jersey: Prentice Hall, Inc., 1967), pp. 278-280.

26 K.C. Brown, op. cit.

of these studies were of short duration and did not account for the complete development of the child over a long period of study. It is also being surmised in these studies that inquiry is synonymous with processes in science. As such, processes are regarded as an inherent part of inquiry and more concern is shown with inquiry generally than with the factors that are part of inquiry processes.

It should also be indicated that the proponents of the "problem solving method", "discovery method" or "inquiry method" have their share of adversaries. Ausubel states this very vividly when he asserts:

> Discovery methods are, by no means, unique in their ability to generate self confidence, intellectual excitement, and sustained motivation for learning. Good expository teaching can accomplish these very same objectives. . . [27]

Educators have continued in the development of the inquiry method of teaching and have moved to the explicit teaching for process. Empirical results to this stage indicate that this may add another dimension to making an individual scientifically literate.

IV. SURVEY OF ATTEMPTS AT PROCESS - APPROACH TEACHING

The possibilities for teaching for process have existed for many years. The NSSE forth-sixth yearbook lists the objectives of the scientific method and outlines some possibilities for teaching. It does however, seem that the processes

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[27] David P. Ausubel, "Learning by Discovery: Rationale and Mystique," ed. Rathsop. cit., p. 259.

were to come about as a by-product of science teaching. It was also noted that probably the potentialities of this approach rested with the teacher. As stated in this yearbook the idea is not new:

> To develop these and other skills of problem solving, it is not necessary for the teacher of science to abandon or sacrifice the content courses as now organized in favor of some radically different plan. A large proportion of high school science lends itself to the purposes here discussed with but a slight change of emphasis and approach. The important factor is a teacher who is alert to the potentialities of the situation as it arises.[28]

It is probable that the emphasis of making the individual more responsible for his education that interest in process became more predominant. The NSSE, fifty-ninth yearbook notes the following:

> The behavioral scientist tends to think of education primarily in terms of the process by which the individual is aided to bring more fully into play the potential of intelligent and constructive behavior which he possesses. Hence, he is likely to think of science education as the extention and more adequate development of children's curiosity through the processes of exploration and learning by experience. In these terms, science education should begin in primary grades and should represent a gradual and sequential development of scientific inquiry.[29]

It was also noted that one needed to teach explicitly for process to obtain the desired behavioral result of an individual with attributes in the scientific method. The NSSE, fifty-ninth yearbook states:

> Studies with some notable exceptions, show that although there is a positive correlation between the amount of factual knowledge acquired

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[28] N S S E , (1947), op. cit., p. 171.

[29] _____, (1960), op. cit., p. 33.

> through science training and the ability to exhibit some scientific attitudes, teaching subject matter alone does not produce significant changes in attitude nor measurably train in scientific method. A few thoughtful studies to the contrary, the evidence, on the whole, is convincing that direct teaching for scientific attitude and of scientific method is more effective than instruction not focused directly upon these outcomes.[30]

The literature seems to indicate that few studies have been undertaken to gain clear evidence that teaching for process is superior in developing scientific literacy. Any evidence to this effect is subjective or concerned with only some minute aspect of the total problem.

To further exemplify this approach to science, Schwab discussed the differences between two styles of teaching. In making the comparison he states:

> In the dogmatic classroom, the role of the teacher was to explain what the book left unclear, and to test the students grasp of what he was told . . . While in the inquiring classroom his responsibility is to impart to the student an art, skill by means of which the student can teach himself. This art consists in knowing what questions to ask of a report of enquiry, when to ask them, and where to find the answers. This kind of skill is learned by doing, by exercise, and is taught by guiding the doing.[31]

With a framework for building a process approach curriculum, with some idea of how to approach the study, and with an idea of the objectives, one may now consider programs that meet these criteria .

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[30] N.S.S.E., (1960), ibid., p. 47

[31] J. J. Schwab, (1962), op. cit., p. 67.

Science - A Process Approach is a program which has been developed through more than five years of extensive research, experimentation, testing, tryout, revision, and evaluation on a nation wide scale.

The Process Approach:

> . . . identifies and undertakes development of the student's competency to engage in activities a scientist pursues - observing, classifying, formulating hypothesis, and the other processes identified by the project. Concomitant with this is the accumulation by the students of a collection of scientific knowledge and facts. Less stress, however, is placed on this than on the accumulation of process competence.[32]

Although an elementary program, it is probably the first to have "processes" for behavioral objectives. The behavioral objectives are analyzed in a hierarchy of developing behaviors, each with its own developmental lessons. This program also includes an evaluation scheme, in which student behavior is continuously evaluated. Since this program does not reflect the true nature of science in that content is not treated as a complete body of knowledge, other programs have attempted to modify this defect. The SCIS[33] (Science Curriculum Improvement Study) program tries to modify many of the shortcomings of Science - A Process Approach and adheres to a philosophy which is perhaps

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[32] American Association for the Advancement of Science, Science - A Process Approach, Commentary for Teachers, 3rd ed., (AAAS miscellaneous Publication 68-7, 1968,), p. 23.

[33] Robert Karplus and Herbert D. Their, A New Look at Elementary School Science (Chicago: Rand McNally and Company, 1967).

more agreeable in terms of process and content. The following is noted about this program:

> The children in this classroom are deeply involved in two important aspects of basic science. On the one hand, they are analyzing, observing, noting details . . . One can refer to these as the processes of science. . .
>
> On the other hand, the pupils are acquiring fundamental concepts about matter and its properties - concepts which are basic, moreover, to the structure of science, and which run like girders through its edifice . . .
>
> The adoption of this philosophy of an approach to science teaching makes impossible the separation of process goals from content goals, or either one from concept development.
>
> . . . Any attempt to separate one from the others usually leads to sterility accompanied by a significant increase in use of words to talk about science and a decrease in activities which allow the individual to experience natural phenomena directly.[34]

It should be noted that both of these elementary programs actively involve the students. This is consistent with Schwab's assertions on teaching for inquiry. In considering programs developed for secondary school pupils, this active involvement of the student is still present when teaching for process.

Verduin[35] gets at the two major objectives that must result from a science learning experience: that of content (concepts) and process (scientific thinking and investigation) through use of a form of programming. After the concepts are identified and structured in a logical order, they are then posed

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[34] Ibid. p. 72

[35] John R. Verduin, Jr. "Modified Programming for Elementary Science," Science Education, LII (March,1968), pp. 167-172.

as problems and various kinds of problem-solving directions are outlined. The entire effort tries to insure that appropriate concepts within a unit of study are discovered by students in the spirit of inquiry.

At the secondary level, Klopfer and Cooley[36] have noted that students generally have not attained a realistic understanding of science and scientists. They developed a series of "History of Science Cases" (HOSC) which uses material drawn for the history of science to convey certain important ideas about the scientific enterprise, scientists, and methods and aims of science. The procedures used are narrative outlines accompanied by marginal questions and notes pointing up various aspects of science illustrated in the story. The units were to be biology, chemistry and physics used with existing courses in high school. Actual experiments and problems are also worked out by pupils. When two of these units were implemented into the normal classroom activities and pupils tested on their understanding of science, significant results were achieved on the understanding of science and scientists.

The criterion instrument for the main analysis was the Test on Understanding Science[37], Form X (TOUS). The test measures the understanding of: (1) the scientific enterprise,

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36 Leopold E. Klopfer and William C. Cooley, "The History of Science Cases for High Schools in the Development of Student Understanding of Science and Scientists," Journal of Research in Science Teaching, (1) (March, 1963).

37 _____, "The Evaluation of Specific Educational Innovations," Journal of Research in Science Teaching, I (March , 1963), pp. 73-80.

(2) scientists and (3) the methods and aims of science. On the TOUS scale (3), which deals with the processes, the experimental group (HOSC) produced a significant difference ($p < .0005$) over the control group in the understanding the methods and aims of science.

To exhibit science in operation, and not to talk about science except as summing up of what has been shown, Schwab[38] developed "The Invitations to Enquiry". These are teaching units that present to the student small samples of the operation of inquiry. Each sample is incomplete. The ommission is a blank to be filled by the student. It may be to plan an experiment, or to control a factor in an experiment, or to draw a conclusion from given data. Thus, the "Invitations to Enquiry" teaches inquiry in two ways. First it poses examples of the process. Second, it engages the participation of the student in the process.

Petrie makes an attempt to teach for process. She refers to this aspect as science inquiry skills and these are described as:

> . . . a series of behavioral tasks representative of each process of learning within the laboratory experience, structured on a hierarchy of learning sets or practices patterned after those developed by Obourn.[39]

In her attempt to develop these skills, Petrie followed a teaching plan that states the science inquiry skill, the student activity, and the expected

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[38] Joseph J. Schwab, Biology Teachers' Handbook (New York: John Wiley and Sons, Inc., 1964), pp. 45-51

[39] Grace G. Petrie, "Teaching Expected Behaviors of Science Inquiry Skills," (Doctoral Dissertation, New York University, 1967), ERIC 68-4792, p. 3.

behavior. The substantive content is taken from the field of chemistry. This approach is significant in that it is somewhat similar to the initial approaches taken by the Edmonton Junior High School Project. Specifically, her lesson format was as follows:

Science Inquiry Skill	Student Activity	Expected Behavior
2. Analyze the problem	Define terms	Write out meanings
4. Organize data	Prepare data sheet	Record data in table

It should be noted that this structure follows a behavioral objective approach and places emphasis on student involvement.

In Edmonton,[40] a science curriculum on the topic of "Matter and Energy,"[41] in which both the syntactical and substantive nature of science are recognized has been developed. Content is structured into manageable units and scientific processes are carefully programmed into each investigation. It is a laboratory-oriented program. The science teaching attempts to present students with a fairly valid representation of what scientists do when they go about doing their research. The student takes an active part in the learning, for it is felt that only by making the student participate in learning science in this fashion

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[40] For a review of the development and theoretical analysis see Mokosch, pp. 25-30.

[41] An unpublished program developed by the Edmonton Junior High School Project, directed by M.A. Nay, see also: "Life Science - A Process Approach" developed by the Life Science Committee (1969) Edmonton Public Schools, Edmonton, Alberta.

would he assimilate a true picture of the character of the scientific enterprise.

V. SUMMARY

The elements of the scientific method or the processes of science have been recognized for some time. While the teaching for this aspect has been an objective of science educators for some time, there was a need for a "particular technique or strategy for bringing about learning of some particular science content."[42] It was not until it was recognized that there is a close organic connection between processes and content and that scientific inquiry is part of science that teaching in science took on a new format. Inquiry teaching recognized a need for process and this recognition has led to programs which make attempts to teach for both process and content. A few methods useful for specific purposes have been devised. It is the purpose of this study to propose a methodology of teaching strategies in which the teaching for science process by inquiry may be resolved.

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42 J. Rutherford, "The Role of Inquiry in Science Teaching," Journal of Research in Science Teaching, II (March, 1964), pp. 60-84.

CHAPTER III

DESIGN OF THE STUDY

I. INTRODUCTION

> . . . the limited significance of much of the research that is carried on; the tendency to ignore in practice pertinent theoretical evidence; and the failure to respect theoretical ideas that emanate from the normal setting suggest that research and development must occur on an interactive continuum.[1]

The present study attempts to propose a methodology for the teaching of the process dimension in science. This is done in terms of instructional modes and strategies to bring about effective understanding and skill in the processes as per "An Inventory of the Processes of Scientific Inquiry."

The development of this methodology was the product of pointed research and field testing, with roots both in theory and function. More specifically, this study tried to identify how the processes were taught by five teachers (a tabulation of what took place in practice). With the help of these experiences, strategies were proposed that may be used in teaching for process. These strategies are developmental in format and in many ways hypothetical, but fit the criterion set out by Parker and Rubin:

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[1] J. Cecil Parker and Louis J. Rubin, Process as Content (Chicago: Rand McNally and Co., 1966). P. 43.

> Moreover, a theoretical insight invariably undergoes modification when subjected to application. For this reason, it would be well to yield the concept of the relationship between the scholar-producer and the teacher-consumer in favor of one that is more mutually cooperative... Such a quest might also give rise to a sort of instructional technology - a collection of teaching procedures that are an amalgamation of research evidence and pragmatic invention, and which are continuously modified in use.[2]

In order to provide an operational framework to this study, and one that provides a logical and orderly developmental sequence, the design was structured in terms of an instructional model. The particular model is based on Engman's operationalization of behavioral objectives.[3]

II. THE INSTRUCTIONAL MODEL

In the teaching of science:

> Judgment about the effectiveness of any given approach or curriculum must be made on the basis of a student's knowledge or cognition of the investigative procedures or processes employed by scientists and the skill he exhibits in using these processes as he learns science. Whereas a process approach in science teaching is dictated by the nature of science, a "behavioral approach" is dictated by the educative process. Expressed in the form of "behavioral objectives," the primary purpose of the behavioral approach is to guide the programming, teaching, evaluation, (and revision) of the science curriculum. It is our contention that most of the new science courses have failed to deal meaningfully and totally with the process aspect or science largely because of a failure to identify objectives in this

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[2] Ibid., P. 43.

[3] Bill D. Engman, "Behavioral Objectives: Key to Planning," The Science Teacher, XXXV (Oct., 1968), pp. 86-87.

domain in a behavioral manner and to specify teaching strategies for achieving them.[4]

To conceptualize this whole educative enterprise and to provide a framework to this study, the model in Fig. 1 was adopted. In Phase I of the model, the process objectives are stated in behavioral terms. These could also be expressed in terms of conceptual schemes and concepts as they relate to science content or to a discipline, and the processes a scientist follows in scientific inquiry. The behaviorally stated objectives would appear separately, although instructionally and in this study these objectives are integrated. This phase is open-ended, for objectives in other facets of the scientific enterprise, e.g. affective attributes of scientists, may be stated. No focus on this aspect was made in this study. Only behavioral objectives in the process dimension were undertaken.

Phase II of the sequence involves the designing of appropriate learning experiences. As noted by the model, the structure of science, modes of instruction, etc. are all factors that have a bearing on the learning-teaching situation. If the stated objective is what is desired as to the outcome of the teaching efforts, teacher plans, etc., strategies must be devised that will result in a mastery of content by a learner, as well as in the development of behaviors characteristic of scientists in the scientific enterprise. This study is concerned with the

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[4] M. A. Nay and Associates, "A Process Approach to Teaching Science," (Edmonton: University of Alberta, 1970), (Mimeographed).

PHASE I

Objectives Stated in Behavioral Terms

Conceptual Schemes and Concepts (relating to content or the discipline)	Processes of Science (cognitive, affective and psychomotor)

consistency

PHASE II

Appropriate Learning Experiences Based on Stated Objectives (Dependent - Upon)

Structure of Science (a) membership and organization (b) substantive (c) syntactical	Instructional Modes Adapted to "process teaching" in terms of Inventory of Processes in Scientific Inquiry.	Teacher Commitment and consciously and continually emphasizing phil. of science and science method	Classroom Organization and Climate Grouping, Discipline, Questions.	Psychology Learning theories Transfer, Communition, Creativity	Resources Instructional and Facilities

PHASE IV

Analysis and Revision

PHASE III

Evaluation of Objectives

Content - in terms of concepts, laws, generalizations, etc.	Process - in terms of the inventory of Process in Scientific Inquiry.

consistency

FIGURE I

AN INSTRUCTIONAL MODEL

development of strategies within the instructional modes which will transform the process objectives to behaviors. The other facets, e.g. psychology, the teacher, etc., with the exception of certain "related factors" were delimited in this study. Related factors, i.e. questioning techniques, motivation, etc., had a bearing within the instructional modes. The model shows the intent of these other facets and their relationships.

Phase III involves the construction of evaluative devices which will ascertain the degree to which the desired behaviors have been achieved by the students. This evaluation will ascertain whether the desired behavioral objectives in content, processes, and other factors that may be considered, have been achieved. This aspect is open-ended, as it corresponds to Phase I. For example, affective behavioral objectives in Phase I would become the same objectives that would be evaluated in Phase III. In this study evaluation was informal and internal as it related to the developmental aspects. The evaluative aspect as intended by Phase III is part of a formal evaluation and is being developed and carried out in a separate study by John MacDonald.[5]

Phase IV concerns teacher analysis of the outcome of a given teaching unit. Regardless of how well statements which satisfy the criteria of behavioral objectives are written, unless there is an understanding of the relationship of the objective to what follows in the other phases, the instruction that may be carried

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[5] John MacDonald, " An Evaluation of a Science Curriculum with Special Emphasis Upon Student Characteristics and Teaching Methods", a doctoral dissertation proposal. (Edmonton: University of Alberta) (Mimeographed), 1970.

out may remain ineffective.

In this model, consistency is a keynote of the whole operation. To guide the consistency and to provide a framework and a structure to the operation, the "An Inventory to Processes in Scientific Inquiry" was used. The inventory pervaded the statement of outcomes that were desired. The inventory also helped to simplify and expedite planning within the instructional mode, for the type of activities must be consistent with the statement of outcomes. Any evaluation must be consistent both with the activities and objectives. The inventory was used to make it possible to develop these aspects logically and sequentially.

The strategies for teaching for process were developed within the operational framework of the instructional model and Parker and Rubin's premise of the "interactive continuum".[6]

III. THE DEVELOPMENT OF THE METHODOLOGY ON THE BASIS OF THE MODEL

A. THE BEHAVIORAL OBJECTIVES

Before a pedagogy may be developed in the methodology of the process approach to science, there is a need for a statement of behavioral objectives.

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[6] J. Cecil Parker and Louis J. Rubin, op. cit. p. 43.

As stated by Anderson:

> Performance objectives are statements which express specifically and in measurable terms an attitude that will be developed or a cognitive or psychomotor skill that students will be able to demonstrate as a result of a prescribed treatment, method, or mode of instruction. In essence, they are expressions of what a teacher hopes his students can accomplish as a result of his teaching.[7]

For this study, the researcher outlined the behavioral objectives in the process dimension. As work progressed, it was noted that science students needed certain basic skills that were associated with the process skills. These were then stated as "Basic Skills in Junior High School Science". This whole dimension became the basis of instruction.

The objectives were written so as to be consistent with the "An Inventory of Processes in Scientific Inquiry". Criteria as identified by Mager[8] were used in the preparing of the process objectives. Specifically, this involved specifying the kind of behavior involved and describing the important conditions under which the behavior is to occur. The writing of the objectives took the "open-ended"[9] form, in which the general type of desired behavior was described rather than insisting on a specific behavior for which a training sequence must be designed.

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[7] Hans O. Anderson (editor), "Preparing Performance Objectives", in Readings in Science Education for the Secondary School (New York: The MacMillan Company 1969), p. 154.

[8] Robert F. Mager, Preparing Instructional Objectives (Palo Alto, Calif.: Fearon Publishers, 1962.)

[9] Albert F. Eiss and Mary Blatt Harbeck, Behavioral Objectives in the Affective Domain (N.S.T.A., D.C.: Washington, 1969) p. 6.

The process objectives reflected the intents of "An Inventory of Processes in Scientific Inquiry". The basic skills were derived from numerous junior high school texts.[10] These were accepted as appropriate for junior high school science for there was concurrence regarding their importance by the researcher, the teachers involved in the study, and the authors of the texts.

B. APPROPRIATE LEARNING EXPERIENCES BASED ON OBJECTIVES

Instructional Modes

The second aspect was concerned with Phase II of the instructional model, that of developing appropriate learning experiences based on the stated objectives. In this phase, only the facet of instructional modes and selected "related factors" was considered. To stay within Parker and Rubin's "scholar-producer and the teacher-consumer" tenet, hypothetical models using different instructional modes were developed to provide learning experiences based on the stated objectives. These were related to the collection of pertinent information on how processes of science were taught by five selected teachers. With cooperative interaction, research evidence, and modification, strategies to provide these appropriate experiences were proposed and developed.

The following instructional modes in science methodology were used

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[10] See: J. A. M. Brock, et al., Patterns and Processes of Science, Texts 1, 2, and 3 (Massachusetts, D.C.: Heath and Company), 1969.

to develop the process aspect:

a. Laboratory

b. Field Studies

c. Demonstration

d. History of Science, Case Study, Case History, Research Papers

e. Audio-Visual-Film, Film loop, Filmstrip, Tape Recorder, Record Player

f. The Lecture and Discussion

g. Invitation to Inquiry

h. Simulation

i. The Project (Pupil)

Within these instructional modes Basic Skills associated with the process dimension, and other "related factors" such as motivation, questions and questioning techniques, grouping and group dynamics, discipline and class management, and structured and unstructured activities were considered.

The strategies -- plans for achieving the goals of learning -- consisted of teaching plans of descriptive and illustrative materials, prepared and modified to involve pupils in the processes of science. By use of the "An Inventory of Processes of Scientific Inquiry" as a framework these lessons were made consistent with the statement of outcome.

A definition of the instructional mode was provided, a rationale for its use in teaching for process developed, and a selected summary of research made. This summary of research was obtained from literature research considered in terms

of the implications for junior high school science.

Teachers, Pupils and Schools

Five teachers and their grade seven classes in five different Junior High Schools in Edmonton made up the population. The teachers chosen were colleagues of the researcher and members of curriculum committees involved in the teaching for process. For this study the teachers attempted the different instructional modes proposed and committed themselves to the following:

a. To teach, Life Science - A Process Approach, chapters one and two and / or content along the conceptual structure of Life Science - A Conceptual Framework [11] in grade seven.

b. With cooperation and consultation, to implement different instructional modes in their teaching. And to, field test hypothetical developments so that reactions of teachers and pupils may be assessed and revisions made.

c. To consciously and continually use the "An Inventory of Processes in Scientific Inquiry".

d. To provide feedback to the study in terms of materials produced and formal reports.

e. To permit the researcher to make observations and tape recordings of lessons taught.

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[11] Life Science - A Process Approach, chp. 1 & 2 and Life Science - A Conceptual Framework were materials produced by the Edmonton Public School Board - Life Science Committee (1969) (J.H.S.), 1969.

In attempting to teach for process within this study, two teachers had two years experience with the "An Inventory of Processes in Scientific Inquiry" and process approach teaching, and the others had three years of experience. Three of the five teachers had been involved in developing process approach curriculum in the last three years. Four of the five teachers held the position of Junior High School Science Coordinator in the school system. Fourteen classes consisting of a total of 373 students were involved in the study.

In terms of science facilities, two schools had science classrooms with a demonstration table in front of the room. To group pupils for investigative work flat top tables were provided. The other three schools had classrooms with four hexagonal 'islands' and the trapezoidal tables. These facilities may be regarded as providing optimum conditions for doing laboratory work at the junior high school level.

In this study, the interaction of researcher and classroom teachers spanned from September 1, 1969 to March 26, 1970.

Inservice Seminars With the Teachers

Inservice seminars were held with the teachers for exchanging ideas, discussing hypothetical developments, and collecting feedback. Nine inservice meetings were scheduled, but only six were held, as other commitments made it impossible for the teachers to attend. These were held approximately every third week, beginning with the initial meeting in the second week of September. In each of these the researcher led discussions on specific instructional modes and outlined ways that processes may be incorporated in the teaching. The researcher

provided present research evidence on the modes, reviewed some of the basic methodology, suggested possible ways of teaching for process, defined limits of the modes and developed or found materials that were useful to the enterprise. Two modes, Invitations to Inquiry and Simulations, were not discussed because of the time factor. The thesis proposal was also provided to each teacher in the study. Experiences with the instructional modes were shared, related factors were considered, and basic skills associated with the process dimension reviewed. Evaluative procedures were also discussed. The researcher also had two informal visits with each teacher at their schools where process approach developments were discussed.

IV. DATA COLLECTION ON HOW PROCESSES WERE TAUGHT

A. REPORTS FROM THE TEACHERS

To provide insight and information for Phase II of the instructional model, data was collected from accounts given by teachers during classroom visits and inservice seminars, and from formal written reports. The Report I, (see appendix B) was used for the first two months of the study. Although providing more of the desired type information, it was too time consuming. The report was revised to consist of the instructional mode and process check-off of the original report and Report II (see appendix B). These reports consisted of teacher assessments of observations and experimentations in their classrooms, providing a record after each lesson was taught of the instructional mode (s) used, the process(es) attempted and how the teaching for the process(es) was carried

out in terms of teacher and pupil involvement. The major emphasis of each report was in answer to the question of "how", in which the teachers were to specifically state the questions asked, how the pupils were involved, and the dynamics of the lesson. These reports were substantiated by materials prepared for pupil use in the classroom wherever possible. Information on related factors was lacking and was obtained primarily in personal discussions with the investigator.

In the analysis of the data obtained from the teacher's reports, a system of classification and a frequency tabulation were used. Each instructional mode was considered in terms of the processes as per the inventory. The percent of time spent by each teacher in each instructional mode was calculated. The percent of processes used in each instructional mode and the overall total were also computed. From the reports, descriptions and illustrative materials were obtained of what teachers did in teaching for each process in any of the instructional modes. These teaching strategies were interpreted by the researcher as to the process dimension being attempted and made part of the methodology for that mode.

B. THE FORMAL CLASSROOM OBSERVATIONS

Formal classroom visits were made to the classrooms of the teachers involved in the study for validating the reports and materials presented by the teachers and their interpretations of the processes. Three visits were made to each teacher at the end of the study. Permission was obtained for making a formal recording of their teaching and for tape recording their lessons. The

formal observational period spanned three weeks and the three visits to each teacher were made in a random manner. That is, the specific visits were not announced, in order to insure as much as possible an observation of the actual activity of the teacher. In the observations one class was visited twice and one once with each teacher involved. The observers were the researcher himself and his colleague.

The observations were structured in that an observational instrument was devised and applied independently by the two observers to the same classroom situation at the same time. It was assumed that the teacher behavior, classroom interaction and interpretations of the processes portrayed during the three formal visits would be similar to the regular teaching pattern of the teacher during the study. This assumption was borne out by the random informal, as well as the formal visits made to the classrooms of the teachers for purposes of testing, discussion, etc.

The purpose of the visits was: (1) to establish an interpretative framework in order to establish some reliance (reliability) on the teachers' reports, particularly in the interpretation of the processes of science; (2) to describe as accurately and objectively as possible the behavior of the teachers and the characteristics of their teaching.

An observational instrument was devised for this purpose. In order that it be as valid a measure of behavior as possible, an attempt was made to fulfil

the three conditions set out by Medley and Mitzel,[12] namely: (1) A representative sample of the behaviors to be measured must be observed. (2) An accurate record of the observed behaviors must be observed. (3) The records must be scored so as to faithfully reflect differences in behavior.

The Observational Instrument

The instrument consists of two parts, (see appendix C) one to measure the process observations, the other to assess the teaching aspect. The "An Inventory of Processes In Scientific Inquiry" was utilized to obtain a representative sample of process behavior. Each of the possible subcategories under the seventeen major processes were listed as possible observations. This insured condition (2) above, as all possible observations were recognized. It was also consistent with the philosophy of the Instructional Model, in that the evaluation of the process objectives was consistent with the behavioral objectives desired and the appropriate teaching strategies. On observations of behavior, Kerlinger states:

> The important clue to the study of the validity of behavioral observation measures would seem to be construct validity. If the variables being measured by the observational procedures are imbedded in a theoretical framework, then certain relations should exist.[13]

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[12] Donald M. Medley and Harold E. Mitzel, "Measuring Classroom Behavior by Systematic Observation" Handbook of Research in Teaching, Gage, N. L. (ed.), (Chicago: Rand McNally and Company), 1963, p. 250.

[13] Fred N. Kerlinger, Foundations of Behavioral Research (New York: Holt, Rinehart and Winston, Inc., 1964), p. 507.

The listing of the observations that were possible was thought to attain an aspect of this construct validity. The instrument required a process judgement to be made every two minutes. A tally for the major processes was made, although secondary ones were marked off. This was felt to add to the construct validity of the instrument in that making a judgement every two minutes assured the investigator of obtaining a representative sample of behaviors. As such, condition (3) above was satisfied. The greater the number of frequencies recorded, the better are the chances of noting differences.

For the other half of the instrument dealing with the teaching aspect, the "Observational Instrument for Science Teaching", developed by Fischler and Zimmer was used.[14] (See appendix C for the modified instrument and definitions of terms). Observations were also made at two minute intervals, corresponding with the process observation. The dominant technique for each major category was recorded, although other activities if observed were checked off. Although the recording of observations was an adaptation of the Fischler and Zimmer instrument, it was felt that the claim that this instrument enables one to differentiate the teaching characteristics of individuals teaching science was still a valid one.

The Observational Instrument, consisting of Part I and Part II, was

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[14] Abraham S. Fischler and George Zimmer, "The Development of an Observational Instrument for Science Teaching, Journal of Research in Science Teaching V (2) (1967-68), pp. 127-137 and an Erratum to this article in VI (4), (1969), p. 387.

subjected to a "trial run" in a classroom outside the study. Both the researcher and his colleague acted as observers. The percentage of agreement between the two observers was 100% with respect to the major categories. The teacher was in complete agreement with the observers with respect to the processes taught.

The formal observations were all done by the researcher and his colleague. Each of the observers applied the instrument independently. Both agreed to observe the same quadrant of the classroom for a quarter of the time allocated to the class period. This made it possible for both the observers to make observations on the same situations and involving the same students at all times. This procedure was thought to insure adequate sampling of pupil behaviors and teacher-pupil interactions. The observers were to make a major observation every two minutes, although secondary observations were also marked in. The permission of the teachers was obtained for the tape-recording of all lessons. These tapes were for the purpose of making further analyses, for settling major observational disputes, and in the development of the criterion for categorization in the event that both observers saw the same thing, but placed the observations in different categories. It was found that the tapes provided the information that made it possible to improve the distinctions and thus obtain better observer agreement. The tapes were most useful in the analysis of teacher questions.

After the teacher taught a lesson he was provided with a check list of all the major science processes (seventeen categories) on which he marked off all the process he consciously felt that he taught. The assumption was made

here that if the process dimension was taught and was to effect a change in the behavior of the students, the observers should be able to identify aspects of this in the lesson. That is to say, if the behavior was not noticed by the observers, this behavior was not, in effect, being translated to the students. The observers agreed to accept the judgement of the teacher if both recorded it as a major observation in a category, or if one observer saw it at least twice as a major category, or if one observer had it as a major and the other as a minor category. This procedure was applied to all cells in the instrument. Any deviation was regarded as a misunderstanding on the part of the teacher.

After the observations were made, the observer reliability (agreement between observers) was estimated. This was done separately for the process aspect and the teaching technique. A Chi Square[15], test of independence (.05 level) was applied to each set of data to provide a measure of discrepancy between the observed cell frequencies (sub-categories) and those expected on the basis of independence. The test considered all cell frequencies (sub-categories) within each major category. It was necessary to use the major categories in the process dimension for it was a case of fewer than 20 percent of the cells having an expected frequency of less than 5, and no cells having a frequency of less than 1.[16] For characteristics of teaching all cells were

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[15] George A. Ferguson, Statistical Analysis in Psychology and Education (New York: McGraw-Hill Book Company, 1966), pp. 200-203.

[16] Sidney Siegel, Nonparametric Statistics for the Behavioral Sciences (New York: McGraw-Hill Book Company, 1956), p. 178.

considered separately, with the exception of the major category of "Teacher Talk", since there were not enough frequencies, a regrouping was carried out. For the process criteria, the seventeen major categories of the inventory were used. A process was recognized as being part of a major category if the two observers noted at least two major observations in the sub-categories of this major category. Although the teachers reported only the major categories, the use of subcategories provided construct validity to the instrument.

There was perfect agreement between the observers on the seventeen major process categories and this outcome became the criterion for judging the reliability of the teachers' perception of processes. The premise used here was that in terms of the three visits, the generalizations derived could be extended to the understanding of the processes in the reports turned in during the six-month study. To ascertain if there was a difference in the interpretation of the processes identified by the criterion and that of all teachers, the Wilcoxon Matched-Pairs Signed-Ranks Test[17] was applied. This provided a preliminary indication of agreement. Applying this test to each teacher was not possible for the number of observations was too small. Criteria for judging the significance of each specific teacher were derived in terms of probability theory.

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[17] Siegel, Ibid., pp. 75-79.

The following probability formula was developed:

$$\frac{{}^{n}Cr \quad . \quad {}^{n_1}Cr_1}{{}^{n_2}Cr_2}$$

where C refers to the combinations; in terms of n, which is the total correct processes as per criterion and r, which is the number chosen correctly (i.e. if the criterion listed 4 processes and the teacher chose 2 of them correctly, the number of possible combinations is $4C_2$, which is 12); n_1 refers to the difference between total process possible (17) and those chosen correctly (n), i.e. number left to make an error; r_1 refers to the number of errors made by the teacher; n_2 refers to the total number of processes (17); and r_2, refers to the number of processes marked off by a teacher.

This test considered the number of correct processes and the number of wrong process that the teacher identified for the total possible in terms of the criterion. This formula was applied to each lesson. The probability was calculated by summing the three numerators and the three denominators and calculating the ratio obtained. The formula was applied to each lesson separately because the number of possible processes as per criterion varied with the lesson. On the basis of this result the reliability of the teachers reports was assessed.

The teaching techniques section (Part II, of the Observational Instrument) was used to supplement the description of the teachers in the classrooms. These results are expresses as percentages of the total. Although patterns were noted, it is difficult to generalize for the total study.

CHAPTER IV

DEVELOPMENT OF MODES FOR PROCESS APPROACH TEACHING

I. INTRODUCTION

The primary task of the science teacher is to structure lessons resourcefully and arrange classroom conditions in such way that the nature of the scientific enterprise, in particular, the scientific mode of inquiry is exemplified. In this study it was science processes which were stressed. This resulted in an emphasis on the use of teaching strategies in which students are involved in "sciencing" or in working on instructional materials which bring out the nature of science.

The development of the instructional strategies started with the stating of the behavioral objectives to be achieved. These were stated in the process domain. Within this domain basic skills for junior high school science were also enumerated. These skills are very much a part of the processes of science, but were identified specifically for the teaching of process. Clue words are provided to specify the specific behaviors that may be desired, when structuring the behavioral objectives for specific lesson plans.

With the objectives clarified, instructional modes and strategies were proposed to provide the appropriate learning experiences as denoted by Phase II of the instructional model. The emphasis is on the instructional modes. Despite

a continuous barrage of recommended innovations, the basic instructional modes used by teachers in science teaching were chosen. It is felt that major improvements need to be made with these modes in the process domain. Furthermore, all modes are part of the scientific enterprise itself and/or of the teaching process.

II. BEHAVIORAL OBJECTIVES IN THE PROCESS DOMAIN

The behavioral objectives in the process domain that were used were the following:

1. Initiation

1. The pupil in observing a phenomena is able to identify and formulate a problem.

Specifically the pupil will:

(a) speculate about a phenomenon.

(b) identify the variables that are part of the problem.

(c) note and make assumptions.

(d) delimit the problem.

2. The pupil will attempt to comprehend background material that has a bearing on his problem.

Specifically, the pupil will:

(a) recall relevent knowledge and experiences.

(b) carry out literature research.

(c) consult people.

3. The pupil can express with certain confidence happenings that will occur because of past observation of their regularity.

4. The pupil is able to express a possible or tentative explanation for a phenomenon.

5. The pupil after doing the preliminary work on a problem designs experimental procedures for collection of data to solve this problem.

Specifically, the pupil will:

(a) define the independent and control variables in operational terms.

(b) define the procedure and sequencing the steps.

(c) identify needed equipment, materials and techniques.

(d) indicate safety precautions.

(e) devise a method for the recording of data.

II. Collection of Data

6. As the situation demands, the pupil will modify his experimental procedures in the course of collecting data.

Specifically, the pupil will:

(a) collect, construct, and set up the apparatus or equipment.

(b) do field work and/or perform the experiment.

(c) identify the limitations of the design and modify the procedure.

(d) repeat the experiment.

(e) record the data.

7. The pupil makes a point of observing information that is selected and believed relevant, serves the design of his experiment or serves the purpose of his solving the problem.

Specifically, the pupil will:

(a) obtain qualitative data.

(b) obtain semi-qualitative data.

(c) gather specimens.

(d) obtain graphical data.

(e) note unexpected or accidental occurrences

(f) note the precision and accuracy of data.

(g) judge the reliability and validity of data.

III. Processing of Data

8. The pupil to make the data more meaningful, has it rearranged, compared, ordered or classified.

Specifically, the pupil will:

(a) order to identify regularities, i.e. scales.

(b) develop relationships through classification.

(c) develop relationships by comparing.

9. To facilitate interpretation and to make it more concise and complete, the pupil systematizes the data graphically.

Specifically, the pupil will:

(a) draw graphs, tables, outlines, charts, diagrams, etc.

(b) as may be required, interpolate, extrapolate, etc.

10. The pupil utilizes mathematical methods as an integral part of data compilation and analysis.

Specifically, the pupil will:

(a) do computations as may be required.

(b) use statistics.

(c) determine the uncertainty in results.

IV. Conceptualization of Data

11. The pupil after considering a body of observations and relevant facts is able to provide an explanation or solution for a phenomenon.

Specifically, the pupil will:

(a) suggest an explanation for a set of data.

(b) derive an inference or generalization from a set of data.

(c) assess validity of initial assumptions, predictions, and hypotheses.

12. The pupil provides the minimum description or action needed to identify an object or event.

Specifically, the pupil will:

(a) state a verbal description.

(b) state a mathematical description.

13. The pupil is able to provide in the appropriate instances

mathematical relationships for expressing scientific relationships.

14. The pupil is able to integrate new discovered relationships with those existing into a new or modified theory.

V. Open-endedness

15. The pupil seeks to substantiate his observable results by further investigations.

Specifically, the pupil will:

(a) increase the level of confidence in the explanation or generalization.

(b) test the range of applicability of the explanation or generalization.

16. The pupil utilizes the insight gained through the analysis and synthesis of a particular problem to predict and solve new problems.

Specifically, the pupil will:

(a) study the effect of a new variable.

(b) consider anomalous or unexpected observations.

(c) will recognize incompleteness and inconsistence in the theory.

17. The pupil attempts to apply the knowledge gained from an investigation.

III. BASIC SKILLS IN JUNIOR HIGH SCHOOL SCIENCE

As the behavioral objectives were being outlined, there emerged a need for the development of certain basic scientific skills. These skills were compiled from texts at the junior high school level and a composite list was prepared to help teachers achieve this objective. The basic skills are to be complimentary to the process dimension, and are skills that were basically believed to be in the realm of the nature of science.

1. The student should exhibit skill in measurement:

   (a) measurement of linear dimensions.

   (b) measuring volumes of liquids.

   (c) measurement of mass (weight).

   (d) timing events (time and rate).

   (e) the use of the metric system.

2. The student should have skill in the use of basic equipment and apparatus, such as the:

   (a) microscope.

   (b) balances.

   (c) thermometer.

   (d) bunsen burner.

3. The student should have an understanding of properties, specifically, color, shape, density, structure.

4. The student should have an understanding of conditions, specifically

such as pressure, environmental temperature, humidity and gravity.

5. The student should have knowledge in the expressing of positions.

6. The student should have a working knowledge in dimensions:

(a) visualizations in three dimensions in space.

(b) working with two dimensions (area).

(c) working with three dimensions (volumes).

7. The student should be able to exhibit understanding in the limitations of science:

(a) error as it applies in science.

(b) significant figures.

(c) tolerance.

(d) ranking.

8. The student has a knowledge of analytical skills, specifically, i.e. acid-base tests, CO_2 tests, etc.

9. The student can exhibit descriptive skills, specifically:

(a) graphing.

(b) scientific diagramming.

The student should exhibit the process dimension or skill in a specific terminal behavior. To achieve this, Blackwood's[1] clue words; the major groupings centering around knowing, manipulating, applying, creating, evalua-

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[1] Paul E. Blackwood, "Science Teaching in the Elementary School," Science and Children, 2:24 (September, 1964), p. 24.

ting and communicating are useful. The complete list is provided below. It should be noted that some categories do not apply in all situations. Prefixing statements with a clue word will describe the terminal behavior in that it will identify and name the overall behavioral act. For example, the behavioral objective might be: "1. measurement of linear dimensions". Specifically for a particular lesson the behavioral objective could be "To measure the dimensions of a cubical mass" or "To report the dimensions of a cubical mass".

CLUE WORDS

Knowing

Observes	Describes	Accumulates	Looks
Identifies	Gathers	Counts	Sees

Manipulating

Measures	Selects	Computes	Weighs
Balances	Instruments	Demonstrates	

Applying

Classifies	Distinguishes	Plans	Ponders
Assigns	Organizes	Compares	Groups
Defines	Estimates	Concludes	Decides
Associates	Equals	Experiments	
Arranges	Sorts	Controls	

Creating

Hypothesizes	Reflects	Incubates	Formulates
Induces	Proposes	Predicts	Interrelates
Deduces	Criticizes	Estimates	Generalizes
Speculates	Conceives	Explains	Forecasts
Analyzes	Invents	Appreciates	Extrapolates
Selects data	Guesses	Infers	Interpolates
Designs experiments	Comprehends	Abstracts	
	Doubts	Synthesizes	

Evaluating

Ponders	Pools data	Doubts	Transposes
Rejects	Recognizes errors	Verifies	Generalizes
Accepts	Equates	Decides	Controls variables
Believes	Distinguishes	Interprets	
Disbelieves	Questions	Criticizes	

Communicating

Tabulates	Explains	Debates	Questions
Graphs	Teaches	Argues	Instructs
Writes	Informs	Describes	Plots
Speaks	Charts	Demonstrates	Draws
Reports	Reads	Compares	

IV. INSTRUCTIONAL MODES AND STRATEGIES

The basic instructional modes used in science teaching are adapted for process approach teaching in this section. Each mode is provided with a definition, followed by a rationale for its use in teaching for process. It was felt that it was necessary to justify the use of these modes as they may be used in teaching for process. The literature was perused to obtain research evidence on any mode, especially as it related to process teaching and the junior high school level. For many of the modes under these conditions, research evidence was lacking, although in other variables and specifics many valuable insights were available. The description and discussion proceeds with the general aspects of the mode. Here again, this was mainly directed to the process objective. Any text on science methodology will point out the "do and don'ts" for any one of the modes, and as such, this aspect was not stressed. However, while

the intention was that all modes be utilized in teaching for process, some are better for one purpose or another, and hence criteria are presented for the use of the instructional modes followed by a strategy, an illustrated lesson, and discussion. It should be remembered these were based as much as possible on the tenets held by the researcher. These include the view that science should be within the students' experience, that content is basic in process teaching, that the student be actively involved in the processes of science and that the student's behavior be guided by the discipline and the professional's procedure.

The lessons presented as examples are based on the three major areas of the junior high school program. Although, the research was carried on within Life Science classrooms, the examples exemplify that process teaching is possible in the Earth and Space Sciences, and in the Physical Science programs in the junior high school.

A. THE LABORATORY

The laboratory is an integral and indispensible part in the pursuit of science. Alternative means, or preferably a combination of instructional modes with the laboratory, can be used to provide the student with opportunities for deepening his understanding of science. It is here that experimentation may be conducted by individuals or groups of students, that demonstrations by the teacher may be performed, that the efforts of field studies may be analyzed and scientific inquiry pursued in part with specially prepared films, slides, or filmstrips.

Definition of Instructional Mode.

Work in the laboratory seems to be synonymous with experiments. Woodburn and Obourn provide a useful insight for this mode when they state:

> Basically, laboratory exercises are done or performed as a means of practice or training. Common usage often fails to distinguish between laboratory exercises and experiments. Experiments are tests or trials, tentative procedures, acts or operations for the purpose of discovering something unknown or testing a principle or supposition. Obviously, laboratory exercises can provide practice or training in designing, operating, and interpreting experiments, but they are quite likely to be contrived pedagogical devices, and, as such, should be clearly distinguished from experimentation as it exists in the pursuit of science. Well designed and conducted laboratory exercises, however, can incorporate much of the spirit and many of the skills of experimentation.[2]

The laboratory mode can also be considered in the functional aspect: that of equipment and facilities; the open field, where nature can be observed; the room equipped with apparatus for conducting experiments and testing observations.[3] The significance lies in the results from the use of the laboratory.

Rationale for its Use in Teaching for Process

A case for the use of this mode in the teaching for process rests on

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[2]John H. Woodburn and Ellsworth S. Obourn, Teaching the Pursuit of Science, (N.Y.: The Macmillan Co., 1965), pp. 366-67.

[3] National Academy of Sciences-National Research Council, Guidelines for Development of Programs in Science Instruction; Report of a Study, Making specific Reference to the Teaching Function of the Laboratory in Secondary School Science Programs, Publication 1093, (D.C.: Washington, 1963), p. 1.

either the psychology of learning or on the whole aspect of the nature of the scientific enterprise. On the former aspect students need to learn by manipulating apparatus, doing the practical and dealing with the concrete. On the function of science, in Schwab's terms, the laboratory in the inquiring curriculum provides a tangible experience of some of the problems dealt with and of the difficulty of acquiring data and provides occasions for the invitations to the conduct of miniature but exemplary programs of inquiry.[4] The study of science in laboratory situations serves a dual purpose. The laboratory provides an avenue where the processes of science can be actively utilized, particularly with an understanding of procedures for scientific investigation, including certain control variables, careful observation and recording of data and the development of inferences. This leads on to the other aspect, the learning of the concepts and facts of science in terms of a discipline.

A Summary of Related Research

The value of laboratory work in the science curriculum has been the subject of numerous studies. This summary will attempt to review some of the comparative studies, for they deal not only with a laboratory method, but also with the demonstration, lecture and discussion methods. For the teacher there

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[4] J. J. Schwab, The Teaching of Science, (Cambridge, Massachusetts: Havard University Press, 1961), p. 53.

are few objectively evaluated research studies that provide clear direction on how laboratory experiences are to be blended with the more formal classwork.

Inductive discovery methods of science instruction generally fail to produce more effective learning than traditional deductive verification methods. Karle[5] found no significant difference between groups taught by the two methods on measures of critical thinking, interest in science, recall of information, or application of principles.

In another study, Oliver[6], used five measures: (1) the acquisition of factual information in biology, (2) overall achivement in biology, (3) the application of scientific principles in biology, (4) attitudes towards science, and (5) attitudes toward the scientist to determine the relative effectiveness of the following three methods for teaching biology: (a) lecture-demonstration, (b) lecture-discussion-demonstration, and (c) lecture-discussion-demonstration - laboratory exercises. No significant differences at the .05 level occurred among the groups on the five measures.

Yager[7], in a similar study to that of Oliver, had students in the

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[5] Paul de Hart Hurd and Mary Budd Rowe, "Science in the Secondary School." Review of Educational Research, XXIV (3) June, 1964, pp. 289-90.

[6] Montague M. Oliver, "An Experimental Study to Compare the Relatvie Efficiency of Three Methods of Teaching Biology in High School." Abstract: Dissertation Abstracts 22:2293; No. 7, 1962.

[7] Robert E. Yager; Harold B. Enger; and Bill C.F. Snider, "Effects of the Laboratory and Demonstration Methods upon the Outcomes of Instruction in Secondary Biology", Journal of Research in Science Teaching, VI (1) (1969), pp. 76-86.

eighth grade study biology with a discussion approach only (non laboratory), with a discussion-demonstration approach (demonstration) and a discussion-laboratory approach (laboratory group). No significant differences between the three treatment groups were noted in critical thinking, understanding science and scientists, attitudes towards biology and achievement in biology. However, students who experience science by performing demonstrations or those experiencing numerous laboratories develop more skill (0.05 level of significance) with laboratory materials and procedures than students who experience neither demonstrations nor laboratories.

Dearden[8], evaluated four methods of teaching a general biology course: (1) individual laboratory work, (2) demonstration laboratory work, (3) the submission by the student of weekly workbook exercises, and (4) a term paper on a selected biological topic. All attended the same lecture situations. The results showed no superiority in any treatment group on measures of attitudes, knowledge, or scientific thinking.

Most of the results presented in the above researches as summarized by earlier work done by Kruglak[9]. He compared the results of instruction by lecture demonstrations and that of instruction with neither demonstrations nor laboratory

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[8] Douglas M. Dearden, "A Study of Contrasting Methods in College General Biology Instruction," Science Education XLVI (1962), pp. 399-401.

[9] Robert L. Ebel, (ed.), Encyclopedia of Educational Research, (4th ed., 1969), p. 1197.

work. Some results do indicate that in laboratory situations, laboratory manipulatory skills and understanding of the use of laboratory equipment were more highly developed.

Murphy[10], in a freshman biology course researched the effects of a 'content centered' approach as compared to a 'process-centered' approach on measures of achievement, scientific attitudes, problem solving abilities and interest in biology. In the 'content-centered' course the student activities revolved around oral and written directions (laboratory manuals); in the 'process-centered' the students applied inductive methods to the solution of major problems which had been identified by either the students or the teacher. On the four measures one method was no more effective than the other.

The open-ended aspect of laboratory experiments is at present being emphasized. In general, gains in outcomes in knowledge of principles, recall of experimental specifics or ability to interpret knowledge showed no significant differences or favored the open-ended method. These studies lend support to the contention that students can take an active part in formulating their experimental procedures without suffering in achievement.[11]

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[10] Glen W. Murphy, "Content Versus Process Centered Biology Laboratories, Part II: The Development of Knowledge, Scientific Attitudes, Problem Solving and Interest in Biology," Science Education LII (2) (March, 1968) pp. 148-162.

[11] Gregor A. Ramsey, and Robert W. Howe, "An Analysis of Research on Instructional Procedures in Secondary Science, Part II - Instructional Procedures." The Science Teacher, XXXVI (4) (April, 1969), pp. 72-81.

From this brief review of research, the effects of laboratory work are not compatible with any pre-conceived notions. It should be emphasized that the majority of research focused on four measures: achievement, interest, problem-solving, and attitudes. The research bears little on the process dimension of laboratory work. Perhaps, instead of the emphasis of the laboratory per se there should be an emphasis upon the nature of the scientific enterprise with research on the use of the laboratory in terms of what these experiences should be, how they should be organized, and where they function best.

General Aspects of the Instructional Mode

A. This instructional mode has its greatest merits if students are able to carry out real scientific experiments or original investigations. For process development, this means that extensive pre-laboratory work is necessary on the part of the pupil. He must define his problems, propose hypotheses, design a way for collecting his data, etc. Extensive post-laboratory work would also be involved, for the pupil must explain his inferences and place the knowledge into his known context. Reliance on open-ended situations provides means for further research.

B. The abilities of the pupils should be considered in the structuring of the laboratory activities. Standardized laboratory exercises of the "cook-book" format may be best suited for the pupils who lack ability for original work. These exercises provide training in following directions, keeping good records, etc. Those who are not ready to do original work may also benefit from this approach.

In the structuring of lessons for process development, such students should be presented with progressively diminishing detailed guidance as they advance in their work. This aspect of guidance requires the good judgement a teacher can provide, for students who are provided with inadequate preparation can create, not only inefficient chaos, but dangerous and destructive situations.

C. The laboratory can serve as a focal point in science teaching. But the lecture, text, film, or discussion should be an integral part of the total teaching situation. A demonstration of new techniques, equipment, or precau - tions in handling strange reagents is part of this mode.

Criteria for Use of Mode

The greatest single criterion in determining the value of a laboratory exercise is the manner in which it is encountered by a student.[12] This implies that if there is equal access to classroom and laboratory facilities, concepts should be programmed so as to reach the "experimentation" stage. Laboratory work holds promise of being an efficient way to present the concept and teach the processes of science. The other criterion that should be considered is whether the exercise is really needed to accomplish what it purports to teach. There is probably little to be gained by doing a time-honored laboratory exercise because it is a part of a customary pedagogical repertory. If some other mode can reduce the time between the concept and the child's understanding it should be consid-

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[12] Woodburn, op. cit., p. 367

ered. If the teaching of the concept and the scientific processes involved call for a laboratory approach, there are values to be gained from using this approach. Therefore in process teaching, if the concept avails itself so that students can gain experience in designing, operating, interpreting and evaluating their own experiments within their abilities, this mode should be used to provide these opportunities.

In the Classroom

To illustrate an approach using the laboratory mode and incorporating the process dimension, a lesson for grade IX physical science[13] will be presented. This lesson will be structured and teacher directed.

Topic: Action of Heat Energy on Matter

Content Objectives (General):

1. Heating or cooling results in expansion and contraction of liquids.
2. Liquids exhibit different rates of thermal expansion.

Process Objectives (Specific):

The Pupil should be able to: (P 1) recall relevant knowledge on expansion, contraction and rate of change in matter.

(P 2) state predictions in terms of this knowledge (It is assumed that thermal expansion of solids preceded this lesson).

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[13] Reference: Introductory Physical Science, Preliminary edition, (Prentice-Hall, Inc.), 1964-65, pp. 29-30

(P 3) state a hypothesis as to the rate of expansion of the three liquids.

(P 4) design (write-out) an experiment to test the rates of expansion.

In this design, the pupil will:

(P4-a) state the independent and control variables.

(P4-b) identify the materials, apparatus and techniques.

(P4-c) define the procedure and sequence of steps.

(P4-d) indicate a safety precaution.

(P4-e) devise a method for recording data.

(P5) set up the apparatus and perform the experiment.

(P 6) observe the rate of expansion in terms of changes in temperature.

(P 7) tabulate his data in a chart format.

(P 8) construct and plot a graph of the data.

(P 9) suggest an explanation for the data obtained.

(P 10) provide an interpretation for the data obtained.

(P 11) integrate this data to his existing theory.

(P 12) seek to explain the relationship between density of the liquids and the rate of expansion.

Basic Skill Objectives:

The pupil should be able to: (S 1) identify this as a time and rate investigation

(S 2) correctly read a Celsius thermometer.

(S 3) outline a format for tabulating his data.

In teaching for process, the lesson should attempt to be part of a scientist's way and part of the scientific enterprise. It is assumed that at the start of the year the topic "What is Science?" had been thoroughly discussed. By so doing, the pupil will have an understanding of the scientific enterprise, and an understanding about the methods and aims of science. When this aspect has been discussed and presented,some form of schema should be devised as a model of the scientific enterprise. With an outline plan, the pupils are also able to follow the steps of scientific inquiry more logically.

In this lesson, reference would be made to Fig. 2, An Operational Structure of Science in Relationship to "An Inventory of Processes in Scientific Inquiry."* It could be assumed that this lesson follows the thermal expansion of solids. Therefore, the "action of heat energy on liquids" would be a "new idea" and "a new problem" in the sequence of steps in the scientific enterprise.

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*Adapted from: Paul F. Brandwein, et al., "A Diagram of a Scientist's Way: His Methods of Intelligence," Life: It Forms and Changes (New York: Harcourt, Brace and World, Inc., 1968), p. 512.

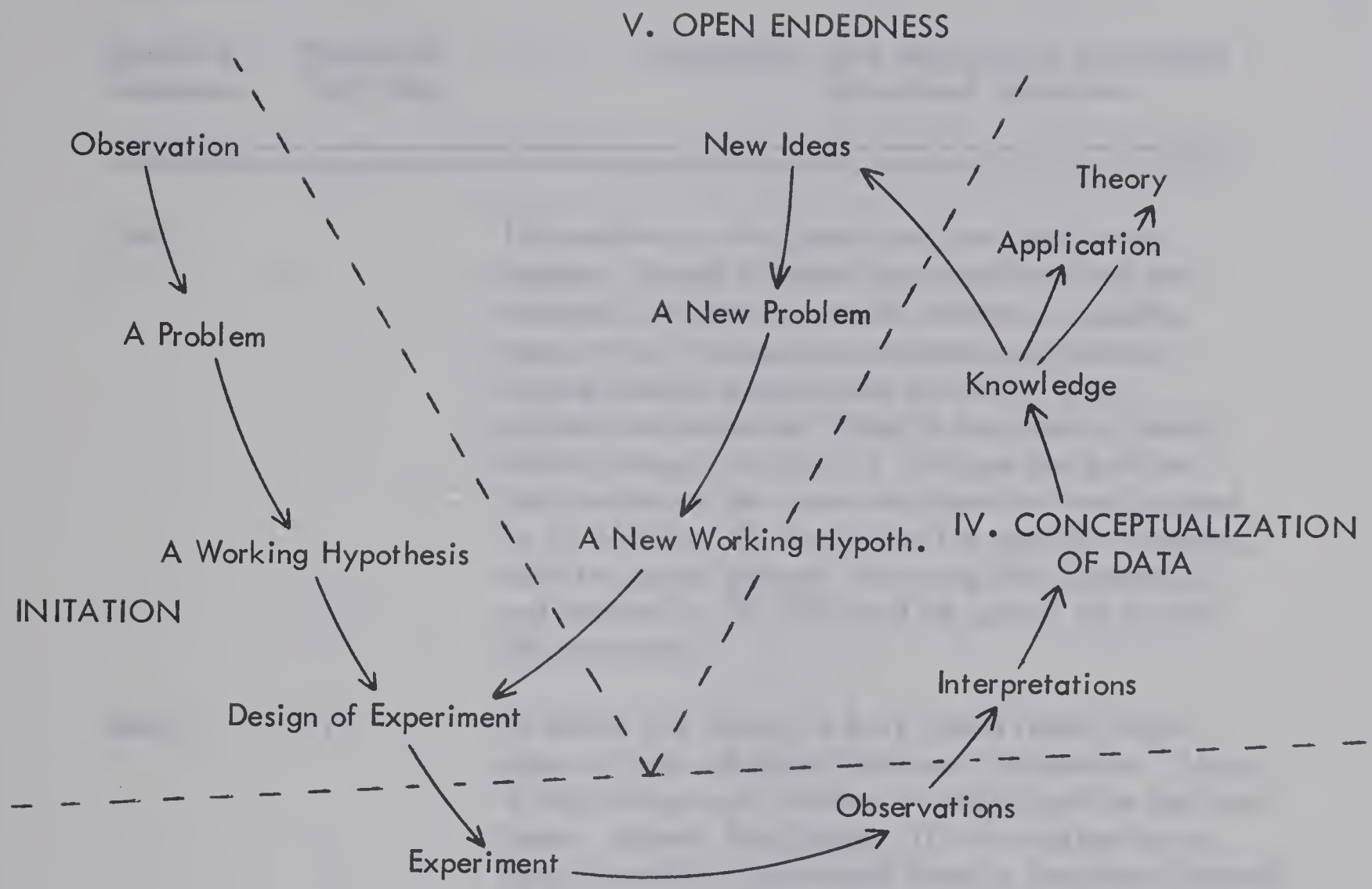

Figure 2

AN OPERATIONAL STRUCTURE OF THE SCIENTIFIC ENTERPRISE IN RELATIONSHIP TO "AN INVENTORY OF PROCESSES IN SCIENTIFIC INQUIRY"

The Lesson

Teaching Sequence	Process & Skill Obj.	Discussion: The obtaining of the desired behavioral objective.
Step 1		The problem for this lesson was provided by the teacher, though it should be emphasized that the teacher is at liberty to do all processes, specific ones, etc. The class was presented with three liquids (water, glycerin and alcohol). The problem was stated as: What is the effect of temperature change on liquids? This was the problem that confronted the class and attention then focussed on its solution. In developing the specific processes, have the pupils actively involved; that is mentally and physically, for they must be part of the scientific enterprise.
Step 2	P1	To obtain this objective have pupils report (write down in their notebooks) relevant information. Much of this background information came from the previous lesson. Briefly they stated: (1) the application of heat to metallic rods caused them to lengthen (expand). (2) Different rods (brass, iron, and nickel alloy) have different rates of expansion.
Step 3	P2	Have the pupils make predictions: What will happen to the liquids if heat is applied? Pupils answered the questions by suggesting that liquids expand. (Past experiences of the therometer, soup boiling over, and the experience gained from working with solids.) Will the liquids expand at the same rate for an equal change in temperature?, is another prediction that can be made. Both, positive and negative predictions were made.
Step 4	P3	The evaluation of predictions leads to more positive statements. Have pupils state hypotheses in terms of the problem. Finally, with the class reach consensus on class hypotheses. The following were stated: H_1: If the liquids are heated they will expand.

Teaching Sequence	Process & Skill Obj	Discussion: The obtaining of the desired behavioral objective.
		H_2: If the constant heat is applied to equal volumes of the liquids, the rate of expansion will be greatest with alcohol, then water and finally glycerin
Step 5	P4	Ask the pupils to design an experiment to test the hypotheses. This may be individual or group effort. Since this lesson is teacher directed, a class design is developed after the pupils spent some time on their own. Direct pupil attention to an experiment with apparatus similar to that in Figure 3.

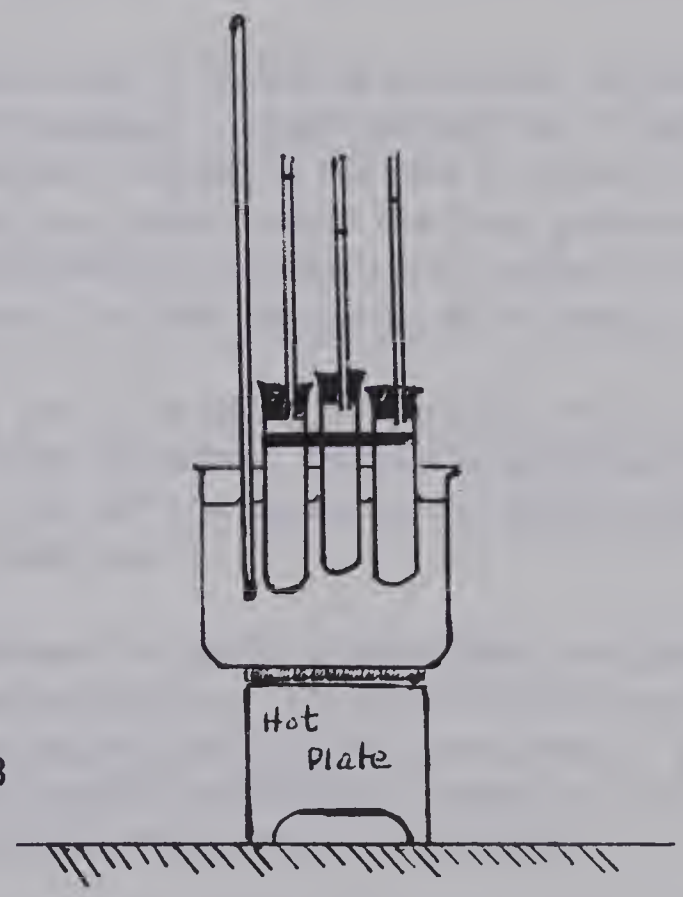

Figure 3

Step 6	P4a	In this experiment there will be a need for an equal supply of heat to all three liquids. Thus, a water bath is necessary and this becomes a variable.
	P4b	Have pupils outline all the needed equipment and apparatus. They will have to be directed to ways of amplifying the expansion, thus the need for the stoppered test tubes and glass tubing.

The Lesson

Teaching Sequence	Process & Skill Obj	Discussion: The obtaining of the desired behavioral objective.
	P4c	The final criterion for the procedure and sequence is that anyone should be able to follow the instructions and perform the experiment.
	P4d	In this experiment what precautions should be taken? The water bath serves as a safety feature for the heating of the alcohol and the glycerin. It should be stressed that if possible, a hot plate should be used.
	P4e S3	Some way of recording the amount of expansion will be necessary. Questions such as: "How will you measure changes in the rate of expansion?" "How are you going to scale the three glass tubes?". Furthermore, the pupils will require to outline a chart for quick tabulation of the results.
Step 7	P5	To get at the manipulatory skills that are developed in the laboratory, the pupils should be requested to "set up" the apparatus and perform the experiment themselves.
	P6, P7 S2	Request the pupils to make their own observations and tabulations. The pupils should know that they are making quantitative observations. It is also important to stress that in observing it is necessary to notice things that are changing.
Step 8	P8	The pupil is then requested to graph his data. Reasons for graphing and techniques of graphing should be discussed. All three liquids should be represented by a different curve design on the same graph.
Step 9	P9, P10	The pupils should be requested to explain their observations in terms of the hypotheses stated. It is here that the student should be given an opportunity to generalize the results of his observations.

	P11	When the interpretations have been discussed, the pupil should be able to add or clarify the knowledge gained on the liquids to the topic of heat energy on matter. This should also provide more information in terms of the Kinetic Molecular Theory.
Step 10	P12	When this investigation is completed a new problem may be attempted, i.e. the relationship of density of a liquid to the rate of expansion. The data may be obtained through direct experimentation or library research and inferences made.

It should be noted that this lesson is directed primarily for process teaching. Within this same lesson, the affective dimension can be incorporated. Questions related to the substantive dimension could be more specifically developed, but it should also be noted that the substantive is very much a part of the syntactical dimension in this lesson.

This lesson attempts to bring out two other dimensions. First, it is structured in terms of the instructional model, in as far as Phase I and Phase II are developed. Second, it attempts to provide a feel for the scientist's way in the scientific enterprise.

B. THE DEMONSTRATION

This instructional mode may be used very effectively for the purposes of developing inquiry and developing the processes of science.

Definition of Instructional Mode

By definition, a demonstration is a planned manipulation of materials and equipment to the end that the students are able to observe all or at least some of the manifestations of one or more scientific principles

operating within a phenomenon.[14]

For many years the demonstration method of teaching science was used primarily for re-inforcement by proving, illustrating, clarifying and amplifying a scientific concept or principle. Although these procedures are still used effectively, an inductive demonstration may be used for the purpose of developing inquiry. As inquiry is developed, it is possible to relate to the processes of science. The silent demonstration was considered, because it is of high inquiry in contrast to the teacher talking demonstration which is of low inquiry.

Sund and Trowbridge[15] make a comparison of the two types of demonstrations:

Teacher-Talking Demonstration	Silent Demonstration
Teacher states purposes of the demonstration	Pupil must discover purpose as the demonstration progresses.
Teacher names pieces of apparatus and describes arrangement	Teacher uses apparatus. Pupils observe equipment and arrangement.
Teacher is manipulator and technician, tells what is being done, points out and usually explains results	Teacher performs experiment. Pupils observe what is being done and then describe results.

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[14] John H. Woodburn and Ellsworth S. Obourn, Teaching the Pursuit of Science, (New York: The MacMillan Company, 1965), p. 321.

[15] Robert B. Sund and Leslie W. Trowbridge, Teaching Science By Inquiry, (Columbus: Charles E. Merrill Books, Inc., 1967), p. 119.

Teacher often points out the things which should have happened and accounts for unexpected results.	Pupils record results as observed. Teacher checks for accuracy and honesty in reporting. Teacher repeats the experiment if necessary.
Teacher summarizes the results and states the conclusions to be drawn. Pupils usually copy the conclusions as stated.	Pupils summarize data and draw their own conclusions based on what they observed. Teacher checks conclusions and repeats experiment if necessary.
Teacher explains the importance of the experiment and tells how it is applied in everyday life	Pupils attempt to answer application questions related to the demonstration.

Rationale for its Use in Teaching for Process

Situations in science such as a phenomenon at variance with ordinary experience, or the teaching of concepts too dangerous or complex to handle, or for which only one set of apparatus is available, or to provide additional aspects of laboratory work, or to teach a specific skill will always exist.

In these types of situations a demonstration can be used to ask students to state or identify a problem, suggest several hypotheses, modify the design of the experiments within the demonstration and interpret the observations which lead to the solution of the problem. Likewise, in this mode, student responses can be elicited that deal with making inferences as a result of the observations, theory building, etc. The demonstration could lead to many open-ended aspects requiring laboratory work, more demonstration (designed), etc.

A Summary of Related Research

For a review of research using this mode, reference may be made to the composite studies made by Oliver (p. 71), Yager (p.71) and Dearden (p.72). These research projects provide little information on what are the best experiences and how they may be blended into the classroom. Furthermore, most of these studies are based on college students. One questions whether the generalizations are applicable to junior high school students. The effect of teaching consciously for process in terms of the scientific enterprise in this mode still needs further research.

General Aspects of the Instructional Mode

Many tested procedures for presenting demonstrations are available. Since a silent demonstration cannot be supplemented or strengthened by explanation, it requires more planning than does the teacher-talking demonstration. The following may be helpful:

a. Fix clearly the process objectives as well as the content objective.

b. Analyze the demonstration into steps of learning. That is, perform the demonstration to explicitly illustrate the processes involved, i.e. definition of the problem, the hypothesis, etc.

c. Display and select apparatus best suited for the demonstration.

d. Perform the experiment so that the beginning point is determined. The steps that follow should show some relation to the processes of scientific inquiry and the scientific enterprise.

Criteria for Use of Mode

Use of the demonstration for process development probably will be more efficient if it causes students to encounter phenomena in such a way that the same intellectual processes are exercised as those that were used in the original identification and description of these phenomena.[16] It is assumed that these processes retain current relevancy. The teacher should be prepared to structure the situation so that the students are able to identify the processes of inquiry that may be exercised.

In the Classroom

TOPIC: General Faulting

Content Objectives: (1) To study overthrust faulting

(2) To explain how a sheet of rock 2000 feet thick could have been moved 25 miles across a rough and irregular thrust surface without completely breaking apart the material in the upper block. In many cases the beds in the overthrust block are as little disturbed as if they had been essentially unmoved.

Process Objectives:

(General) (1) Formulation of Problem

(2) Hypothesis

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[16] Woodburn: op.cit., p. 323.

(3) Observation

(4) Interpretation

(5) Theory Building.

The Lesson (A Silent Demonstration)

Different theories explaining the development of thrust faults would have been presented. (Stress and strain, push and pull, gravity sliding). Each of them have evidence for their rejection. A silent demonstration is performed to present another current theory. This demonstration also has a close analogy to the actual happening.

Process Dimension	The Teacher Does	The Pupil Sees
	Materials and Apparatus 1. protractor 2. glass to build an inclined plane 12" x 48". 3. Ring stands and bars placed at one end of the incline plane to vary the height. 4. several soft drink cans with the self openings. 5. Pail of ice cubes with a few cans in the ice. (This should be kept away from pupil view).	
Problem Identified	1. Places an empty can on the glass plate at one end. Raises the incline so that the can slides to the pull of gravity. Fixes the height	The apparatus and its arrangement in terms of the total design. The can slides down at an X number of degrees of incline.

Process Dimension	The Teacher Does	The Pupil Sees
	of incline. Measures of angle with the protractor	
Fixes Mentally, Hypotheses are formulated by the students.	2. Lowers incline to original level. Washes down the glass plate with a soap and water solution. Now places the same can at the end of incline, raises the incline so that the can slides down.	
Observation at each step of the demonstration.	Measures the angle with protractor. (The use of the same can need not be too obvious). Dries incline.	The can slides down at less than X number of degrees of incline.
	3. Sets incline lower than the last reading (10° - 15°). Measures with protractor.	The change in method of arrangement. The same incline has been preset. The can is known to <u>not</u> slide from the previous two observations.
	4. Places <u>cold</u> can on incline with opening to the bottom. Waits a few seconds. (The exposure of the cold can can be a <u>clue</u> provided at the end of demonstration if pupils have difficulty in interpretation.)	They observe the same can, not really knowing that it has been extensively cooled, slide down.
	5. Repeats the above by lowering the incline a few more degrees.	The can does not slide down or has difficulty in doing so.
	6. Lowers the incline to 2° -3° . Wets down the incline plane. Places <u>cold</u>	The can slides down. They also saw that it did not slide down in step 2 at

Process Dimension	The Teacher Does	The Pupil Sees
	can with opening to the bottom.	this low incline.
Interpretations	7. Asks pupils to consider what they have seen and to draw inferences and generalizations.	Generalization 1. The angle of incline has an effect on mass sliding. 2. Lubrication reduces the force of friction and mass slides at a lower incline. 3. (If students realize the effect of the cold air in the can). Air as it is warmed up expands, and this provided a lifting force to the can, reducing pressure between the can and the surface of the plate.
Theory Building	8. Asks pupils to use their ideas in explaining a current theory of overthrust faulting.	

A class discussion would follow to clarify the substantive aspects. This would provide more answers to the different theories on overthrust faulting.

C. THE AUDIO-VISUAL MEDIA

In recent years there has been virtually an "explosion" in the amount of Audio-Visual material available for the teaching of science. If suitable material is accessible, the teacher can adapt some of it to teach the process of

science.

Definition of Instructional Mode

The use of audio-visual media (film, filmstrips, film loops, record players, tape recorders) in inquiry situations provides substitutes for first-hand experiences in the development of processes of science.

Rationale for its Use in Teaching for Process

Some of the media that have been produced are useable directly for inquiry in teaching the process of science. Suchman's program called Inquiry Development in Physical Science, makes use of A.V. media. Silent film loops are used in which students have to arrive at a suitable explanation of the depicted phenomenon. Inquiry filmloops and slides by the Biological Sciences Curriculum Study, are designed to develop students' understanding of some specific process or combination of processes of science.

In other situations, the value of the mode lies in the fact that it is possible to effectively integrate the media into the instructional sequence and attempt to combine the character of science with its content through the involvement of students in the teaching of science as a process. Besides bringing various phenomena into the classroom, it is possible to trigger or bring data to bear on an hypothesis, clarify the design or interpretations of an experiment, aid in the validation of inferences, or provide avenues for further research.

A Summary of Related Research

Audio-visual aids have become valuable supplements in the instructional

process, but like any other instructional procedure, they need thorough evaluation before any generalization can be made.

When achievement in content is the criterion under consideration, use of film as an instructional aid has not produced significant gains. Anderson, Montgomery and Moore[17] compared achievement of groups taught introductory chemistry by means of films with that of groups given nonfilmed instruction. They found that compared with the approach using films, the conventional non-film method produced superior results in measured achievement.

In a similar study, Popham and Sadnavitch[18] discovered that students taught by a filmed chemistry course achieved as well as those taught by the conventional method, but students in conventional physics achieved at a higher level than that of physics taught by film.

Kazem[19] used informational expository films and historical dramatic films to teach scientific method to biology students. He found that the expository

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[17] Kenneth E. Anderson, Fred S. Montgomery, and Sid. F. Moore, "An Evaluation of the Introductory Chemistry Course on Film." Science Education 45: (April, 1961), pp. 254-69.

[18] James W. Popham and Joseph M. Sadnavitch, "Filmed Science Courses in the Public Schools: An Experimental Appraisal." Science Education, 45: (October, 1961), pp. 327-35.

[19] Mohamed K. Ahmed Kazem. "An Experimental Study of the Contributions of Certain Instructional Films to the Understanding of the Elements of Scientific Method by Tenth-Grade High School Biology Students". Abstract: Dissertation Abstracts 21: 3019; No. 10, 1961.

films produced more gain in understanding than the dramatic films, and that using both films together produced the greatest gain in understanding.

In the development of attitudes via the movie film medium Wickline[20] found no significant change in attitudes towards science or scientists, although there was improvement in understanding science. The results may be useful for process teaching.

Gentry[21] investigated the relative effectiveness of teaching concepts through the single-concept loop. He used ordered and random-concept sequences taught by expository narration. While the differences were not statistically significant, a trend favored discovery narration for less able students and expository narration for the more able students.

Gibbs,[22] in another study in this area found that the ability to construct relevant hypotheses in Biological Science Curriculum Study (BSCS) biology was improved significantly in classes using the film loops. This aspect could have potential for process development, as these film loops are structured to develop certain aspects of inquiry. It might be generalized that A-V media have desirable aspects on the learning process. As for process development, these

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[20] Ramsey, The Science Teacher, op. cit. 75.

[21] _____, op. cit. 75.

[22] Ramsey, op. cit. p. 75.

media must be structured for the achievement of such objectives and research is necessary on how best to integrate this aspect into the teaching strategy.

General Aspects of the Instructional Mode

It is difficult to generalize for all the media that might be used in this instructional mode. Woodburn and Obourn provide an insight here as they state:

> The important thing is that a lesson has a well-ordered structure and that the instructor be ready to have the structure he chooses for any lesson be subjected to the best that is known about the psychology of the learning process, and examined to determine whether it parallels or contradicts the structure, tactics, and strategy of the pursuit of science.[23]

This instructional mode can be utilized in developing the structure of science along cognitive and affective domains. To provide a structure for teaching the use of An Inventory of Processes in Scientific Inquiry may be implemented. It should be stressed that the use of any of the media in the traditional sense, that is, for introduction of a topic (motivation), review, a vicarious field trip, etc. can be maintained, but can also be utilized so as to develop scientific process through inquiry.

A film, for example, may be used in the following ways:

(1) As an introduction to the spirit of science and the development of the skills of the scientific approach (processes).

-- A useful film will have material in which the organization of content is in

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[23] Woodburn and Obourn, op. cit., p. 293.

a succinct and capsulized form.

(2) To develop some specific process or combination of processes. (It is hoped that the film would have the ability to present raw data to students, rather than a summary of someone else's conclusions.)

-- Process: Background Information-Showing of natural phenomena from places not accessible for class visitation.

-- Process: Observation -- Slow-motion or time-lapse photgraphy, which demonstrates phenomena too rapid or too slow for first hand observation.

-- Close-up sequences that may be superior to a live demonstration.

-- Process: Design or Interpretation -- Films showing experiments not feasible in the average laboratory because of time and expense.

-- Process: Interpretation or Developing a Theory -- Animated sequences which help clarify difficult concepts.

(3) As an evaluative aspect in assessing behavioral change. Assessment may be in the cognitive and affective domains as well as in terms of the inventory of processes in science.

Criteria for Use of Mode

Use of this mode should be considered in terms of what the specific medium used does to first, enhance the learning process and second, how it contributes to the scientific enterprise. As such, A-V media are very much a part of the other instructional modes. In process development, one should consider how the A-V media may be used to bring the day's phenomenon before the class, to provide data bearing on a phenomenon, to test the consistency of

interpretations made, or to facilitate achievement of any aspect of the process dimension in scientific inquiry.

In the Classroom

To utilize the A-V instructional mode, two illustrative lessons, one making use of a 16 mm. film and the other of a filmstrip will be presented. Both are used to develop specific processes and at the same time to provide substantive material.

TOPIC: Density

Content Objective (General): Fluids exert a buoyant force on floating or submerged objects.

1. The buoyant force exerted on a body by a fluid is equal to the weight of the fluid the body displaces.
2. Density is the mass of an object per unit of volume.
3. Specific gravity is the ratio of the density of a substance to the density of water.

Process Objectives (Specific):

The pupil should be able to:

(P1) formulate a problem after observing a phenomenon.

(P2) state important and relevant knowledge shown in a film that is helpful to solve the problem.

(P3) design an experiment to arrive at a

solution to the problem.

(P4) record observations that provide information to help the design of the experiment and the solving of the problem.

(P5) state a mathematical relationship for the scientific relationship developed.

(P6) state verbally a description of the events. i.e. buoyancy, density and specific gravity.

Skill Objectives:

The pupil should be able to: (S1) through measurement techniques –

(a) weigh the metal objects on a pan balance.

(b) find the volume of these metal objects by displacement of water.

The Lesson (Using a Film)

Teaching Sequence	Process & Skill Obj.	Discussion: The obtaining of the desired behavioral objective.
		The students are confronted with three metallic objects, different shapes and greyish in color (pieces of lead, iron, and steel.)
1	P1	The students are posed with the questions: "What can you observe about these objects?" For the process of observing, any one or several or all of the sense -- sight, touch, hearing, taste and smell may be used. Observing requires more than mere visual inspection. It means reporting the shape, color, number, position, order and so on. It means odor or taste or sound. It is important to remember that the characteristics are directly perceived by the senses.
2		Ask the pupils to identify and state problems arising from these observations. This should again be related to the model in figure 2 (p. 79). A problem that may arise is the following: Are metallic objects that look alike but have different size and shape of the same material?
3	P2	To provide the necessary background information and help in the designing of an experiment the first part of the film Archimedes' Principle was shown*.
4	P4	The pupils are requested to write down all information that may be helpful in solving the problem.

*Film: Archimedes' Principle - Encyclopedia Britannica Films. This film dramatizes the problem that led to Archimedes' famous experiment on buoyancy and recreates the experiments under conditions that show the development of this principle. He uses this principle to test the purity of the gold in his king's crown.

The Lesson (Using a Film)

Teaching Sequence	Process & Skill Obj.	Discussion: The obtaining of the desired behavioral objective.
5	P3 S1, a & b	With the experiences from the film have the pupils design an experiment applicable to the metallic objects. The key factors in this design will be to obtain the weight of the objects and their volume. If these are new skills they should be demonstrated by the teacher.
6		When the design is completed the students should perform the experiment. It is also possible that in this section, they may note limitations in their design and modify the procedure. The teacher should provide only guidance and pupils should attempt the experiment from their own experiences. The teacher should insure a design is outlined by his students and might review whether important factors have been considered.
7		As students perform the experiments, observations should be recorded. This should lead naturally into explanations and generalizations.
8	P5	Once data has been gathered, students should be asked if any relationships exist that may be used to compare the objects. Possible answers will be a ratio factor of Weight/Volume or Volume/Weight.
9	P6	At this stage the required vocabulary may or may not be identified. It probably is more important that verbal descriptions of what relationships exist be identified. As this is not an "original" discovery, the teacher may direct pupils to library research, to which labels may be attached, and words like buoyancy, density, and specific gravity become part of the vocabulary. Again, many open-ended aspects are possible, i.e. specific
10		gravities of liquids and the different explanations of specific gravity, i.e. density of substance/

The Lesson (Using a Film)

Teaching Sequence	Process & Skill Obj.	Discussion: The obtaining of the desired behavioral objective.
		density of water; weight of substance/buoyant force of water and depth rod sinks in water/depth rod sinks in liquid.

The Lesson (Using an 8mm. film loop)

An actual lesson utilizing the film loop is presented. In this situation each pupil had planted some bean seeds and was required to make observations over a two week period and from these records explain the stages of bean growth. After a discussion at the end of the two weeks, many puzzling questions remained. Some students reported that certain observations were not possible; i.e. observations were made daily, but it was difficult to actually see the growth, etc. This led to the idea that further evidence was needed to elaborate the initial situation.

Students expressed the need for some unique photographic techniques such as time lapse photography, etc.

To get more data and around the need for more sophisticated procedures, Ward's film loop Bean Germination was shown several times. (This film loop, through the time lapse technique, shows the bean growth of seven days in three and one quarter minutes).

The pupils then were asked to make observations and interpretations in terms of data from the film loop. This evidence was used to add to or modify their original generalization. The complete investigation as presented to the

pupils follows:

Process Objective and Discussion	The Investigation
The formulation of the problem is developed through class discussion.	Problem: To seek further evidence to explain bean germination and growth.
The design is provided and discussed.	Design for Collection of Data: View Ward's film loop "Bean Germination". In this film loop a single picture was taken on the average each five minutes of a bean growing for a week. As a result an apparent speed-up of growth of 7200 times occurs. The film loop represents the data obtained from doing the experiment.
	Note: The occasional flashes of light you see on the screen are caused by water being added from time to time.
(P1) The pupil should be able to record observations that are more precise and accurate.	Observations: Record the growth stages by noting carefully the factors or processes in the growth from the beginning of growth (germination) to the development of the new plant.
(P2) The pupil should be able to explain the growth of a bean seedling in terms of the observations.	Interpretations: From your observations suggest reasons for the way growth of a bean seed takes place.
Questions to guide students' thinking were provided. Some will require pupils to observe the film loop again.	The following questions may be helpful: 1. Why did the beginning of growth start at the "seed opening"? 2. Suggest reasons why no development begins before stem and leaf development. 3. The seedling formed an arch (the stem) as it was coming out of the ground. Is this habit an advantage to the plant?

Process Objective and Discussion	The Investigation
	4. What is that "fuzz" on the lower end of the root?
(P3) The pupil should be able to describe and explain the growth of a bean seedling with more confidence	Further Evidence: How does your new knowledge compare with your previous interpretations?

What about the Audio-Visual materials which have been or are being produced, but not directly for inquiry or teaching the process of science. It is possible to use some of them for this purpose. In the use of this type of material, the students' attention should be directed not only to the concepts involved, but also to how these concepts evolved -- the technique of "inquiry into inquiry" which Schwab[24] suggests.

D. HISTORY OF SCIENCE, CASE HISTORY, AND ORIGINAL RESEARCH PAPERS

Definition of Instructional Mode

Any material in which the content consists of major scientific ideas that are followed through in detail through the use of the historical perspective, with original writings and accounts of activities may be used. These are selected and organized so that they amplify and provoke the development of

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[24]Schwab, The Teaching of Science, op. cit., p. 65.

important understandings about the processes of science, the scientific enterprise, and the characteristics of scientists.

Rationale for its Use in Teaching for Process

This approach makes it possible to provide the student with first hand contact with original scientific writings, and to see fundamental discoveries through the eyes of their discoverers -- the humanizing involvement, the thinking and frustrations, and essential honesty of the scientific efforts that are part of the scientific process. Students are able to stand alongside the scientists as they worked in their laboratories. The learning can be dramatized and essential substantive material presented. The student can become aware of the processes involved and perhaps engage in clearer thinking and experimenting in his own projects. If he knows and understands the thinking and experimenting that led to the older information, it might be an easier task for him to build on that foundation, and assimilate the new findings.[25] Furthermore, this method can exemplify and direct students' attention to many of the intangible aspects of science. These aspects include understanding of the nature of scientific inquiry, science as an enterprise with the interplay of social, economic, technological, and psychological factors in its progress, and scientists as people -- their personalities and human qualities.

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[25] Melvin Berger, "Using History in Teaching Science," The Science Teacher, 30 (VII) (November, 1963), p. 26.

A Summary of Related Research

In a study at the junior high school level Wachs[26] reported the following:

(1) The study of source papers in science by the method described in this investigation (developed historical documents with directive questions based on the readings), is an effective means of developing seventh grade students' understanding of the nature of science and scientists.

(2) The method. . . is equally effective. . . with seventh graders of average and high ability.

(3) This method is equally effective with seventh grade girls and seventh grade boys.

(4) It is possible to bring about significant growth in seventh graders' understanding of the nature of science and scientists without loss of subject matter achievement.

Therefore, it could be inferred that the processes of science can be developed by this approach very effectively, for this is very much a part of the nature of science and scientists. It should also be noted that content objectives can be maintained.

Carrier[27], in a study involving three classes of students who have completed the seventh grade attending a summerschool of six weeks duration

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[26] Stanley Wachs. "An Evaluation of a Method of Study of Science Source Papers by Junior High School Students as a Means of Developing Their Understanding of the Nature of Science and Scientists." Eric Microfilm ED 025418.

[27] Elba O. Carrier, "Using a History of Science Case in the Junior High School," Science Education, XLVI (5) (December, 1962), pp. 416-425.

reported that:

(1) The teachers with their subject-matter orientation increased the difficulty of achieving an approach which stressed the methods of science and scientists, rather than the results of science.

(2) It is difficult, in terms of vocabulary and reading levels of junior high students, to simplfy the presentation while maintaining scholarly standards. The use of direct quotations from scientists and the effort to generate possible abstractions of science "intangibles" by the student himself, undoubtedly made it difficult for any but the more able readers to follow the development comfortably.

(3) Results indicate that history of science material results in increases in scores at the $p < .05$ level in the Test of Understanding Science (TOUS).

The findings in this study lend support to the opinion maintained by the researcher that an understanding of "What is science?" is an important facet in teaching for process. It is also necessary to have difficult scientific documents translated into literary works that will encompass the tonality of the original and be at a reading level for junior high students. That is, the syntactical dimension should be maintained and the materials are prepared for the junior high school student.

General Aspects of the Instructional Mode

When anhistorical article meets the substantive criteria on a topic under consideration, properly executed, it may provide an opportunity for students to rediscover, at least vicariously, the scientific process by retracing the classical

episodes. The following points might be noted:

(a) When structuring a study of this type choose an episode that has an adequately documented history and one in which the characteristics and traits of the scientist at work are vividly portrayed.

(b) Structure the material with a detailed treatment of the precise events and circumstances that formed the clues leading to the new hypothesis or glimpse of a possible discovery or invention. Report, if possible, early phases of the investigation, the blind groping or unplanned coincidences from which arose a flash of insight. At the same time provide and identify the events and circumstances that may have contributed to the flash of insight. Incorporate into the presentation the tactics and strategy reflected in the design, conduct, interpretation, and validation of whatever experiments or investigations are included in the design. Here reproductions of original writings, sketches, and diagrams are very useful.

(c) Structure questions which will emphasize the impact of the processes involved. The affective and social (cultural aspects) could very well be interpreted at this time. Finally, relate this historical development to the topic that is being presently considered.

Criteria for Use of Mode

When the substantive aspect can be developed with an episode that clearly identifies the spirit in which the scientist worked, the tactics and strategy used in forming the structure of his procedures (the syntactical dimension), and the immediate and ultimate relationship between his work and other facets

of the total culture, the history of science, case study, or original research paper mode should be part of the teacher's repertory.

In the Classroom

There are many ways of involving students in inquiry using this instructional mode. The "Inquiry into Inquiry", a technique proposed by Schwab is a type of activity that can be challenging and help students understand the processes of science. By critiquing scientific papers and other reports they can discover the variety of logical patterns in scientific investigations carried out by scientists.

TOPIC: Embryology or Reproduction

Content Objective: The topic of spontaneous generation sets into perspective one dimension as applicable to the topics of embryology or reproduction.

Process Objective: This case history develops the importance of experimentation and observation. Within this frame of reference, the problem is stated, a hypothesis formulated, an experimental test is carried out and inferences and generalizations made. Further experimentation is carried out to remove doubt and application to problems in society provided.

Experiments on the Generation of Insects by Francesco Redi[28]

Although content to be corrected by any one wiser than myself, if I should make erroneous statements, I shall express my belief that the Earth, after having brought forth the first plants and animals at the beginning by order of the Supreme and Omnipotent Creator, has never since produced any kinds of plants or animals, either perfect or imperfect; and everything which we know in past or present times that she has produced, came solely from the true seeds of the plants and animals themselves, which thus, through means of their own, preserve their species. And, although it be a matter of daily observation that infinite numbers of worms are produced in dead bodies and decayed plants, I feel, I say, inclined to believe that these worms are all generated by insemination and that the putrefied matter in which they are found has no other office than that of serving as a place, or suitable nest, where animals deposit their eggs at the breeding season, and in which they also find nourishment; otherwise, I assert that nothing is ever generated therein. . .

At the beginning of June, I ordered to be killed three snakes, the kind called eels of Aesculapius. As soon as they were dead, I placed them in an open box to decay. Not long afterwards, I saw that they were covered with worms of a conical shape and apparently without legs. These worms were intent on devouring the meat, increasing meanwhile in size, and from day to day I observed that they likewise increased in number; but, although of the same shape, they differed in size, having been born on different days. But all, little and big, after having consumed the meat, leaving only the bones intact, escaped from a small aperture in the closed box, and I was unable to discover their hiding place. Being curious, therefore, to know their fate, I again prepared three of the same snakes, which in three days were covered with small worms. These increased daily in number and size, remaining alike in form, though not in color. Of these, the largest were white outside, and the smallest ones, pink. When the meat was all consumed, the worms eagerly sought an exist, but I had closed every aperture. On the nineteenth day of the same month some of the worms ceased all movements, as if they were asleep, and appeared to shrink and gradually

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[28] M.L. Gabriel and Seymour Fogel, Great Experiments in Biology (Englewood Cliffs, N. J.: Prentice Hall, Inc., 1955), pp. 187-189.

to assume a shape like an egg. On the twentieth day all the worms had assumed the egg shape, and had taken on a golden white color, turning, to red, which in some darkened, becoming almost black. At this point, the red, as well as the black ones, changed from soft to hard resembling somewhat those chrysalides formed by caterpillars, silk-worms, and similar insects. My curiosity being thus aroused, I noticed that there was some differences in shape between the red and the black eggs (pupae) though it was clear that all were formed alike of many rings joined together; nevertheless, these rings were more sharply outlined, and more apparent in the black than in the red, which last were almost smooth and without a slight depression at one end, like that in a lemon picked from its stalk, which further distinguished the black-egg-like balls. I placed these balls separately in glass vessels, well covered with paper, and at the end of eight days, every shell of the red balls was broken and from each came forth a fly of gray color, torpid and dull, misshapen as if half finished, with closed wings; but after a few minutes they commenced to unfold and to expand in exact proportion to the tiny body, which also in the meantime had acquired symmetry in all its parts. Then the whole creature, as made anew, having lost its gray color, took on a most brilliant and vivid green; and the whole body had expanded and grown so that it seemed incredible that it could ever have been contained in the small shell. Though the red eggs (pupae) brought forth green flies at the end of eight days, the black ones labored fourteen days to produce certain large black flies striped with white, having a hairy abdomen, of the kind that we see daily buzzing about butchers' stalls. . .

I continued similar experiments with the raw and cooked flesh of the ox, the deer, the buffalo, the lion, the tiger, the dog, the lamb, the kid, the rabbit; and sometimes the flesh of ducks, geese, hens, swallows, etc., and finally I experimented with different kinds of fish, such as sword-fish, tuna, eel, sole, etc. In every case, one or other of the above-mentioned kinds of flies were hatched, and sometimes all were found in a single animal. Besides these, there were to be seen many broods of small black flies, some of which were so minute as to be scarcely visible, and almost always I saw that the decaying flesh and the fissures in the boxes where it lay were covered not alone with worms, but with the eggs from which, as I have said, the worms were hatched. These eggs made me think of those deposits dropped by flies on meats, that eventually become worms, a fact noted by the compilers of the dictionary of our Academy, and also well known to hunters and to butchers, who protect their meats in Summer from filth by covering them with white cloths. Hence great Homer, in the nineteenth book of the Illiad has good reason to say that Achilles feared lest the flies

would breed worms in the wounds of dead Patrocles, whilst he was preparing to take vengence on Hector.

Having considered these things, I began to believe that all worms found in meat were derived directly from the droppings of flies, and not from the putrefaction of the meat, and I was still more confirmed in this belief by having observed that, before the meat grew wormy, flies had hovered over it, of the same kind as those that later bred in it. Belief would be vain without the confirmation of experiment, hence in the middle of July, I put a snake, some fish, some eels of Arno, and a slice of milk-fed veal in four large wide-mouthed flasks; having well closed and sealed them, I then filled the same number of flasks in the same way, only leaving these open. It was not long before the meat and the fish, in these second vessels, became wormy and flies were seen entering and leaving at will; but in the closed flasks, I did not see a worm, though many days had passed since the dead flesh had been put in them. Outside on the paper cover there was now and then a deposit, or a maggot that eagerly sought some crevice by which to enter and obtain nourishment. Meanwhile the different things placed in the flasks had become putrid and stinking; the fish, their bones excepted, had all been dissolved into a thick, turbid fluid, which on settling became clear, with a drop or so of liquid grease floating on the surface; but the snake kept its form intact, with the same color, as if it had been put in but yesterday; the eels, on the contrary, produced little liquid, though they had become very much swollen, and losing all shape, looked like a viscous mass of glue; the veal, after many weeks, became hard and dry.

Not content with these experiments, I tried many others at different seasons, using different vessels. In order to leave nothing undone, I even had pieces of meat put under ground, but though remaining buried for weeks, they never bred worms, as was always the case when flies had been allowed to light on the meat. One day a large number of worms, which had bred in some buffalo-meat, were killed by my order; having placed part in a closed dish, and part in an open one, nothing appeared in the first dish, but in the second the worms had hatched, which changing as usual into egg-shape balls (pupae), finally became flies of the common kind. In the same experiment tried with dead flies, I never saw anything breed in the closed vessel.

This article is an excellent example of a research paper that was written by the scientist himself. Though others could be more historical in

nature, each type has its merits. The historical approach makes it possible to present more of the cultural and societal factors. However, a personal account of a scientist's experimentation might provide us with more insight into the scientist himself.

For the junior high grades, a clarification of some of the vocabulary would be necessary. The process aspect could be developed by a series of questions. A generalized format which is applicable to the research reports, case histories, and the like follows:

The Processes	Possible Questions in the Process Dimension
Identification and Formulation of Problem	*What was the question the scientist was concerned with? Was the problem stated clearly? How did the investigator limit his problem?
Background information	What previous knowledge was useful to this scientist's investigation? Was this evidence useful? Was it possible that other kinds of evidence should have been considered? Which?
Prediction	What information did the scientist have from past experience that provided clues to stating a hypotheses? * What initial guesses did this investigator make?
Hypothesis	* What was the hypothesis that the scientist finally selected? How does this hypothesis relate to the design of the experiment?

The Processes	Possible Questions in the Process Dimension
Design for Collection of Data	*What plan was used to answer the problem? What were the variables that were involved? What controls were used in the experiment? Could other techniques have been developed for gathering the data? Can you design a simple experiment to confirm the scientist's interpretations?
Procedure	*Outline the procedure used? Could you make any improvements? Would it be possible to do this experiment to confirm the scientist's data? *Did the scientist change his procedure and why? Did the scientist repeat the experiment?
Observing and Observations	*Were qualitative and quantitative observations made? Are verbal descriptions, diagrams, etc. available? Did the scientist observe an unusual happening?
Organizing the Data	How were comparisions made? How did the scientist organize his data? Did the scientist make use of graphs, charts, etc.? Would other methods of organization of data have made for more understanding?
Representing Data Graphically	How was the presentation of data made explicit?
Treating Data Mathematically	What calculations were involved? Are they correct?

The Processes	Possible Questions in the Process Dimension
Interpreting the Data	*What interpretations did the scientist make from his data? Could other interpretations have been made? Does the interpretation fall within the limits of the hypothesis and the problem? Is more data necessary to solve the problem?
Formulating Operational Definitions Mathematical Relationships Theory Building	Does a scientist provide a definition or formula that is part of science knowledge today? What knowledge from this investigation added to the substantive dimension in science? How did this help in the advancement of science?
Seeking Further Evidence	*What further experiments did the scientist do to justify his conclusions? What were the results of these other experiments? Does the scientist have a more conclusive answer to the problem?
Identifying New Problems	What unexpected observations did the scientist note? *What new investigations did the scientist undertake as a result of the original work? What prior knowledge did the scientist sense was necessary before his original problem could be answered?
Applying the Knowledge	How did the scientist proceed to help mankind with his discovery? How did society benefit from the results of the experiment?

The questions marked with an asterisk (*) could be applied to Redi's article. It should also be noted that this article has many facets showing the

operation of a scientist in the scientific enterprise. (See Fig. 2). With an organized class discussion many of the processes can be practically portrayed and the nature of the scientific enterprise depicted. In many instances these original experiments can be reproduced in the classroom. This extends understanding of the nature of science, namely the idea of reproducibility. It should be noted that an important substantive concept is also developed.

E. INVITATIONS TO INQUIRY

Definition of Instructional Mode

Invitations to inquiry consist of individual problems of controllable length and difficulty which take off from particular passages of text and make use of what the text has taught.[29] In each sample, the operation of inquiry is incomplete. There is a blank, an omission which the student is invited to fill. This omission may be the plan of an experiment, or a way to control one factor of an experiment. It may be the inferences to be drawn from given data. It may be an hypothesis (or any other process in terms of the inventory) to account for data given.

Rationale for its Use in Teaching for Process

The Invitation to Inquiry teaches inquiry in two ways. First, it is

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[29] Joseph J. Schwab, "The Teaching of Science as Inquiry", The Teaching of Science (Cambridge: Harvard University Press, 1964), p. 96.

possible to pose example after example of the process itself. Second, it engages the participation of the student in the process. Further, to teach science as inquiry means:

(1) To show students how knowledge arises from interpretation of data.

(2) To show students that the interpretation of data -- indeed, even the search for data -- proceeds on the basis of concepts and assumptions that change as our knowledge grows.

(3) To show students that because these principles and concepts change, knowledge changes too.

(4) To show students that, though knowledge changes, it changes for good reason -- because we know better and know more than we knew before.[30]

Note the aspect of show, this is not mere telling, the need is to exhibit science in operation, not to talk about science except as a summing of what has been shown.

A Summary of Related Research

The researcher is not cognizant of any research evaluating lessons on an Invitations to Inquiry instructional mode. A lesson was presented using

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30 J. J. Schwab, Biology Teachers' Handbook (New York: John Wiley and Sons, Inc., 1963).

Invitation 3: Seed Germination,[31] dealing with the topic misrepresentation of data and was found to be an excellent way to present specific process objectives. It also had a motivational value. It is necessary, however, to structure questions that are direct, for there seemed to be a hesitancy in answering open-ended questions. In the trial classroom, pupils had difficulty in expressing their answers in written communication. Yet in the discussion that followed the pupils expressed their answers well.

General Aspects of the Instructional Mode

Invitations to Inquiry can be written for students of differing ability levels. It should be remembered that this method stresses the development of the cognitive abilities. Structuring of the lesson in terms of the inventory makes it possible to involve students in any or all of the processes. Sund and Trowbridge[32] suggest the following in writing an invitation:

(1) Decide what your objectives are, either in subject matter or understanding science as a process or both.

(2) State a problem related to your objectives. The idea for problems can come from actual scientific research reported in journals.

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[31] J. J. Schwab, BSCS Biology Teacher's Handbook (New York: John Wiley, 1963).

[32] Sund and Trowbridge, op. cit., p. 137.

(3) Devise questions which give students opportunities to set up experiments, make hypotheses, analyze and synthesize and record data. Stress the understanding of science as a process and the cognitive skills involved.

(4) Write the invitation as a series of steps. Insert in different parts of it additional information to help the students progress in depth into the topic or methods of research.

By providing the necessary structure, these experiences could be vicarious experiences in how a scientist goes about solving problems.

Criteria for Use of Mode

A. This method may serve as a motivator to process(es), or act as a different mode of inquiry (in comparison to a laboratory orientation). By studying the projects, which may be used to present substantive material, the students should be able to see science as a process, as well as gaining insight into the limitations of science and developing confidence in their ability to become more scientific.

B. The "Invitations" may be used to teach a specific process or processes, i.e. hypothesizing, representing data graphically, etc.

C. They can still have a laboratory orientation or be part of an inquiring discussion

D. When much time is required for the collection of data or equipment, and for some problems, this becomes insurmountable, an "Invitation" may be furnished to the student in which the essence of the invitation to inquiry consits of Processing the Data, Conceptualization of Data or Open-endedness.

E. The "Invitations" may serve as challenging material for the gifted

student or those who find it difficult to come up with their own problems in project work, or in open-endedness in investigations.

In the Classroom

TOPIC: Nutrition

Content Objectives (general):

1. Food is any substance which, when absorbed into body tissues, yields materials for the production of energy, the growth and repair of tissue, and the regulation of life processes.

2. Six classes of substances are considered as foods.

Process Objectives.

1. The pupil should be able to construct a graph to represent a given table of data.

2. From a report of observations provided and the graph drawn, the pupil should be able to describe and interpret the results in relation to the problem.

In this lesson, many variables (proteins, fats, etc.) may be removed from a diet and the results of the deficiencies studied. This may require a large number of experimental animals and a long period of time. An "Invitation to Inquiry" was used to overcome some of these limitations and still provide opportunities for process development.

Invitation to Inquiry[33]

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[33] Based on a project reported in: Ruth Wenner, Search and Research, (Chicago: Natural Dairy Council, 1964), pp. 9-11.

Problem:

To find out what physical effects the lack of protein in a diet has on albino mice, Mus musculus.

Background Information:

Over the years there has been extensive work in the field of nutrition. Pioneers in experimentation with protein nutrition have been Dr. T. B. Osborn and Dr. L.Mendel. Dr. Osborne was a leader in the studies that showed there are many different proteins in food. He learned that some proteins are better in promoting growth than others. Dr. Osborn and Dr. Mendel conducted feeding experiments with rats that led to the discovery that certain amino acids, the building blocks of protein, are responsible for the differences in maintaining life and promoting growth (1). The lack of protein in a diet causes a stunting of the rate of normal growth (2).

Proteins are described as "complete" if they contain all the essential amino acids (those that maintain life and promote growth), "incomplete" if they lack certain amino acids. Meat, fish, poultry, eggs, milk, cheese contain complete proteins (2).

When he was a freshman, another boy at our school (3) did an experiment with mice in which he fed his control group table scraps approximating his own diet, his experimental group received only a soft drink and potato chips. As expected, his control group remained in better health than his experimental group. However, because there were so many essential food factors missing from the experimental group, it was difficult to make any useful interpretations.

After a short time he returned both groups to a standard mouse diet but made no effort to keep them separated or otherwise identified. Several weeks later one mouse died of unknown causes. Some three or four months later two of the remaining three, being kept in the school laboratory, developed subcutaneous tumors in their hips. One died, the other was chloroformed when it became apparent that recovery was impossible. The fourth remained healthy. It was tempting to ascribe development of the tumors to the deficient diet, but incomplete records made any meaningful connection impossible.

Design for Collection of Data and Procedure:

A pair of adult mice was obtained and mated. Eight offspring of the first litter were used in the experiment. The experiment began when the offspring were three weeks of age. Two males and two females were used in the test group; and two males and two females in the control group. The experimental and control diets were purchased from a biological supply house as matched protein free and protein sufficient diets. The mice were cared for carefully. They were housed in individual cages to minimize the spread of diseases, should any arise.

Water was given freely through watering tubes. The cages were cleaned daily.

On February 14, 1961, the experiment was begun. Length and weight of the mice were measured on the first day and on the same day of every week thereafter for twelve weeks. At the end of five weeks the experimental group showed numerous signs of ill health, and, for this reason were placed on the same protein sufficient diet as their littermate controls.

Parents	
X	Y
Male	Female
Littermates	
x_1	x_3
x_2	x_4
Male	Male
y_1	y_3
y_2	y_4
Female	Female
Control Group	Experimental Group

Observations:

Table I shows the body weight records of the mice, and Table II shows the records of measurement in lengths. Note, however, that in spite of having been given a protein sufficient diet after the 36th day, three of the four experimental mice died before the end of the experiment.

There was a marked difference in the texture and smoothness of the hair in the two groups. The hair growth, as evidence by gains in weight and length, and by the death of three of the four experimental mice during the experiment. The fourth died about a week after the termination of the experiment. The control group remained healthy and in good condition throughout the experiment.

The cause of death in the first mouse, B-4, was unknown. The three remaining test mice, B-1, B-2, and B-3, developed tumors. We think death may have resulted from the tumors.

Interpreting the Data.

(To the Student)

1. From the background information what results were expected from the mice on the deficient diet?

2. What did the results of this experiment show?

3. Why are the severe effects of the diet not evident in growth retardation until the second week?

4. What result was not really expected? Can you explain it?

5. Does this investigation provide sufficient data on the protein diets? Is this important?

Seeking further evidence; new problems; application.

1. Do you have other questions as a result of the review of results?

2. Is the knowledge from this experiment applicable to daily living?

This same lesson taking a different format could get at other aspects of the process dimension. Factors such as the following could be discussed:

1. What is a control?

2. Which was the control group in this experiment?

TABLE I

WEIGHTS, IN GRAMS, OF MICE ON PROTEIN SUFFICIENT DIET (GROUP A) AND PROTEIN DEFICIENT DIET (GROUP B)

DAY	1	7	14	21	28	35	42	49	56	63	70	77	84
A-1 m	7.5	10.0	14.0	17.0	18.7	21.0	22.5	23.0	23.5	23.7	23.7	24.0	24.0
A-2 m	6.5	10.0	14.2	17.5	20.0	21.2	25.0	26.0	26.5	26.5	26.2	26.2	26.0
A-3 f	7.0	9.0	15.0	16.7	18.0	22.5	22.7	23.0	23.2	23.2	24.0	24.0	26.5
A-4 f	6.0	9.5	14.0	18.0	20.0	21.5	21.7	23.2	24.5	27.5	27.0	27.5	27.0
Average	6.7	9.6	14.3	17.3	19.2	21.6	23.0	23.8	24.4	25.2	25.2	25.4	25.9
B-1 m	6.5	8.5	8.7	8.0	11.0	9.0	12.5	17.0	15.0	18.0	deceased Apr. 21 . . .		
B-2 m	7.2	8.5	8.7	7.2	8.7	7.0	8.5	12.0	14.0	14.0	16.0	19.0	17.5
B-3 f	6.5	8.5	8.5	8.5	8.5	7.5	9.0	14.0	14.5	15.0	deceased Apr. 23 . . .		
B-4 f	7.2	10.0	10.0	7.2	9.0	7.0	7.2	--	--	--	deceased Mar. 30 . . .		
Average	6.8	8.9	9.0	7.7	9.3	7.6	9.3	14.3	14.5	15.6	16.0	19.0	17.5

TABLE II

LENGTH, IN INCHES, OF MICE ON PROTEIN SUFFICIENT DIET (GROUP A) AND PROTEIN DEFICIENT DIET (GROUP B)

DAY	1	7	14	21	28	35	42	49	56	63	70	77	84
A-1 m	4.25	5.00	5.75	6.00	6.25	6.62	6.62	6.87	7.00	7.12	7.12	7.12	7.25
A-2 m	4.12	4.87	5.62	6.00	6.25	6.75	6.75	7.12	7.25	7.25	7.25	7.25	7.25
A-3 f	4.12	5.00	5.75	6.12	6.37	6.87	6.87	7.00	7.12	7.12	7.12	7.12	7.12
A-4 f	4.25	5.00	5.87	6.25	6.50	6.87	7.00	7.12	7.25	7.37	7.37	7.37	7.37
Average	4.19	4.97	5.75	6.09	6.44	6.77	6.81	7.03	7.15	7.21	7.21	7.21	7.25
B-1 m	4.37	4.50	5.00	5.00	5.12	5.12	5.25	5.37	5.50	5.75	deceased Apr. 21. . .		
B-2 m	4.25	4.75	5.00	5.00	5.00	5.00	5.00	5.12	5.50	5.50	5.75	5.87	5.87
B-3 f	4.00	4.25	4.75	4.75	5.00	5.00	5.00	5.25	5.37	5.50	deceased Apr. 23. . .		
B-4 f	4.25	4.75	5.00	5.00	5.00	5.00	5.00	--	--	--	deceased Mar. 30. . .		
Average	4.22	4.56	4.94	4.94	5.03	5.03	5.06	5.25	5.46	5.58	5.75	5.87	5.87

3. What is the hypothesis?

4. What is growth?

5. What factors in this experiment were used to determine growth?

6. Are the data complex for this problem?

7. What other data could have been obtained that would strengthen the experiment?

If possible, this should be an actual experimental situation.

F. THE PROJECT

Definition of Instructional Mode

The term project is used simply to indicate a problem, usually involving the use of apparatus and materials, undertaken by an individual or group.[34]

a. They involve an element of inquiry.

b. They are essentially the activities of individuals. If in groups, each number is allotted responsibility for a particular aspect of the work[35]

The inquiry is therefore 'guided' not 'open-ended' in the sense that

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[34] Walter A. Thurber and Alfred T. Collette, Teaching Science in Today's Secondary Schools, 3rd ed. (Boston: Allyn and Bacon, Inc., 1968), p. 536.

[35] W.H. Dowdeswall, "Teaching Science through Projects," The School Science Review, L I (Sept., 1969), p. 169.

the pupil seldom, if ever, has the opportunity of forming a problem for himself and trying to solve it using his own resources.

Rationale for Use in Teaching for Process

The project makes it possible for the pupil to do his own research in totality and take responsibility for it. (This probably is the major "product" of teaching for process.) Since genuine inquiry is involved, the students have scope for creativity and experiences as practiced by scientists.

The instructional mode is excellent for pupils of varying abilities and interests. Gifted students could pursue projects in a normal classroom situation. (The contention remains that all students should be required to do projects).

Furthermore, this approach may be used for the "open-endedness" of the "core" investigations that take place in the classroom.

Summary of Related Research

In project work the hope is for greater integration, increased purposefulness, and more intensive motivation for further study. In the process approach it is hoped that skills would be provided that would help the student to develop his education after formal learning.

The results of research on the effectiveness of the project method are not particularly encouraging.[36] It should be noted the criteria again are measures of achievement. We need research on the superiority of the project

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[36] Gage, (ed.), Handbook of Research on Teaching, op.cit., pp. 1145-1148.

method on measures of motivation, resourcefulness, and other affective and process dimensions. One aspect noted in project work is that favourable outcomes result more often when close contact with an instructor is retained.

General Aspects of the Instructional Mode

It should be stressed that doing the research which the project method demands requires proper guidance, selection, and interpretation of information, knowledge and ideas. Although little of the research at the junior high school level will be "original", the practice provided by this mode has many implications in training for the future. At this level, research problems may be chosen by the pupil himself from a list of problems to be solved. If at all possible, only the question should be presented, for little is to be gained from an inquiry that is complete, except perhaps for manipulatory activity.

The use of the inventory is useful in directing the steps of the research which may take place throughout a project. In the early stages a classroom project should be attempted to introduce the pupils to the processes, to give an idea of the scientific enterprise and introduce pupils to the independence that project work provides.

Further, in the evaluation of these projects, creativity should be stressed rather than the simple copying of a model from the textbook.[37] To provide training as well as serving an evaluative purpose, the project report

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[37] Nathan S. Washton, Teaching Science Creatively in the Secondary School (Philadelphia: W.S. Saunders Company, 1967), p. 236.

should be of a formal nature.

It should be emphasized that the project can involve students not only in experimental research situations, but also in the form of library research, which may be regarded an instructional mode in itself.

In the planning for project work, a time schedule should be implemented. Although this is probably not the way a scientist operates, students need training in setting perspectives for accomplishment.

Criteria for Use of Mode

The project method should be employed if the objective is to develop excellent investigative procedures for inquiry, that is, to develop the processes of science as well as the intangible aspects of the scientific enterprise and scientists. With individualization being in the vogue, what better way to provide for the needs of individuals or for small groups of students? It should be for the intellectually gifted, the highly interested, or even the science shy.

In the Classroom

There are many investigations that may be done by the project method. The project ideas chosen should lend themselves to the many processes as outlined in "An Inventory of Processes in Scientific Inquiry". Essentially, in a basic form this implies: (1) selecting a problem, (2) doing library research, (3) establishing a hypothesis, (4) making a plan or design, (5) carrying out the plan and collecting and organizing the data, (6) drawing generalizations and inferences and (7) presenting a report of the investigation. In reality the student's project

differs from the scientist's project only in degree of sophistication.

There are pupils in our classrooms who are interested in project work, but not necessarily of the "experimental" nature. As such they might be interested in doing a library research project. Problems for these papers may be assigned and the questions directed. Freilich[38] specifies the use of specific questions falling into three main groups: biographical, topical, and experimental. The biographical questions help develop the social background of the great scientists, the topical questions are related to current science, and the experimental questions deal with actual experiments. Although this type of project probably does less in the development of processes, important library and communication skills may be developed and creativity displayed.

Associated with projects are science clubs, fairs and assemblies. These activities provide avenues for displaying creative efforts to fellow students and the public. It is through project work that many of the counterparts of practicing scientists becomes possible.

G. FIELD STUDIES

Definition of Instructional Mode

The field trip has been defined as the:

> out-of-the classroom experiences, primarily for the purpose of

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[38] Florence G. Freilich, "The Library Research Paper in High School Science Classes," The Science Teacher, XXXIII (9) (Dec. 1966), pp. 46-48.

> observing natural phenomena which cannot be brought into the classroom or which, because of their immediacy, are best studied in the natural setting.[39]

The field trip or study should not be thought of in terms of a "nature walk" or an excursion that involves long distances. The immediate local resources, the school ground or neighborhood park or a natural environmental setting (this being the best), may be areas of field studies. Formal field excursions to zoos, or natural history museums and the like are natural learning experiences and provide an incomparable learning environment. The immediate area may be more productive, simply because the class can return repeatedly, collectively and individually, to re-examine what they have seen.

Rationale for its Use in Teaching for Process

The field studies, besides bringing the natural environment into the scope of the pupils' learning experiences, have another very important function in scientific inquiry. Field studies are very much a part of life and earth science courses. It is in these disciplines that the field trip can be utilized for the important goal of gathering of basic data. With this aspect students get a chance and should do the things that a professional field investigator would do. Thus students can become involved in the total scientific process and, as a result, an excellent way of teaching for process may emerge.

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[39] Louis I. Kuslan and A. Harris Stone, Teaching Children Science: an Inquiry Approach (Belmont, California: Wadsworth Publishing Company, Inc., 1968), pp. 262-263.

A Summary of Related Research

Perkins suggests that as a result of a research in field study techniques at an elementary level:[40]

> ... firstly plan and conduct a study with one large group, then in future field trips have separate problems for two or three smaller groups and finally after experience should individual experiments be permitted.

The elementary techniques could very well apply in the seventh grade at the junior high level.

Besides the administrative problems involved in teaching by field trips, Perkins in his study also notes the following:

A. Teacher Problems

(1) Feeling of insecurity in science areas.
(2) Lack of understanding of purposes and methods of field studies.
(3) Lack of skill in visualizing, planning, or demonstrating subjects suitable for study.
(4) Failure to exploit natural correlations.
(5) Lack of evaluation standards for studies.
(6) Large amount of time needed initally for individual and group planning and for building the background necessary to insure a reasonable amount of success with individual ventures.

B. Pupil Problems

(1) Difficulties associated with unaccustomed freedom to plan and work in individual directions.
(2) Poor or inadequately developed habits of observation, measurement, recording or reporting.

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[40] William D. Perkins, The Field Study as a Technique in Elementary School Science, Science Education XLVII (5) (Dec., 1963), pp. 485-489.

(3) A tendency to choose problems too broad for satisfactory completion.
(4) Difficulties in forming useable questions, stating problems, or developing ideas.
(5) A tendency to meet from systematic procedures once they are established.
(6) Difficulty with multiple variables.
(7) Difficulty drawing and expressing conclusions.

It should be emphasized that pre-field trip instruction is important in field trip instruction. Delaney[41] reported results that showed that two thirds of the students, those possessing average and less than average academic ability, were shown to have benefited significantly from pre-field trip instruction. It could be surmised that the total pre-planning etc. of a field study has beneficial effects in terms of process teaching .

Benz[42] conducted an interesting study comparing the relative values of two teaching methods, namely: (1) the use of field trips and (2) the use of slides of the region covered by the field trip. Experimental evidence indicated a superiority on the part of the field trip, though gains were seen in both treatments.

General Aspects of the Instructional Mode

Good field trips are centered around specific problems. An effective field trip is one that does not involve many different problems at the same time.

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[41]Arthur A. Delaney, "An Experimental Investigation of the Effectiveness of the Teachers Introduction in Implementing a Science Field Trip," Science Education, L1 (5) (Dec., 1967), pp. 474-481.

[42]Grace Benz, "An Experimental Evaluation of Field Trips for Achieving Informational Gains in a Unit on Earth Science in Four Ninth Grade Classes," Science Education, XLVI (I), pp. 43-49.

To teach for process field trips should be planned which require maximum amount of student involvement. When problems have been raised which would be best handled in a field trip situation, e.g. ecology studies in life science, or measuring stratigraphic sections, making simple geologic maps and making quantitative studies of factors involving stream velocities in earth science, pupils should be very much a part of the planning. This is where preliminary work in background reading and in the design of the experiment plays an important role. Even on short trips pupils should carry out all preparations -- e.g. equipment, materials, dress, etc. for this would be emulating the professional in his field.

To summarize, the field trip serves at least two important functions in scientific inquiry:

(1) to provide the pupil with basic data obtained only in the field situations.

(2) to have the pupil become part of the total scientific enterprise that would be carried out by a professional in his field.

Relative to these two major functions, let us look at some of the ways in which field studies help to make science live for students.[43]

(1) Field studies can provide an intimate and comprehensive understanding of the total environment and serve to show that scientific endeavors are inseparable from other aspects of life. The student becomes

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[43] Paul DeHart Hurd, Teach Science Through Field Studies, how to... Instructional Aid, N.S.T.A., 1965.

aware of the interrelationship of school, home, and community. Field studies bridge the gap between school and "everyday living", as well as between the textbook and other learning materials read in school.

(2) Field studies, properly planned and executed, have the characteristics of research: students assume the responsibility for defining problems and then investigating, collecting, and evaluating pertinent information. Much of the value of field work lies in careful observation, purposeful interviewing, accurate recording, and in making critical appraisals.

(3) Field studies supply learning with a social setting; they enable students to make social and economic as well as scientific interpretations from their understanding of science concepts. Students may also have an opportunity to develop skills as responsible members of a group, to demonstrate self-direction, and to practice leadership skills. Some of the value of field studies is found in the organization, execution, and evaluation of activities assumed by members of the class. Through these cooperative endeavors, students grow in personal-social relations. These activities help students develop their ability to accept responsibility and to appreciate the worth of purposeful planning.

(4) Field studies offer a chance for people outside the regular teaching staff to contribute to the learning in the school. Community interest in the school thus increases, school-community relations improve, and the bond between school and community is strengthened. Field study programs display the school to the community as well as interpret the community to the school.

(5) Field studies provide an opportunity to study the practical applications of science. Principles of science in the classroom are exemplified in an industrial process viewed in a manufacturing plant or a laboratory. Development and utilization of hybrid corn on a farm or in a manufacturing plant, for example, becomes an achievement in agricultural chemistry, genetics, and technology. Students see scientists, engineers and technicians, and learn about occupations requiring science courses as a background.

(6) Field studies, well planned and executed, improve both learning and retention by providing greater student motivation, a variety of sensory approaches, a correlation of learning experiences, and a sense of realism which clarifies the meaning of concepts. Field study activities stimulate student reading and class discussions which can make significant contributions to learning.

(7) Field studies planned for out-of-school time provide constructive activities and stimuli for the family to do things together. In this way parents share in the learning activities of their children.

Criteria for Use of Mode

If a student engages in a sufficient number and variety of field trip studies in a scientific inquiry framework he will develop many of the processes of science.

A. Essentially field studies should be considered as analogous to the work in the science laboratory. Although they take place in the active world, they offer an endless series of problems to be investigated and provide for experiences in scientific inquiry.

B. A well planned field study provides for all of the "Inventory of Processes in Scientific Inquiry" to be employed. The student may begin with a background of general knowledge in science represented by concepts, basic ideas, laws, theories or principles. He acquires understanding and skill in observing, measuring, analyzing, classifying, comparing, communicating, and experimenting. Collected data will become meaningful in terms of a selected problem. In dealing with this problem, he may be required to formulate hypotheses, devise models, develop quantitative relationships, make inferences, manipulate variables and recognize irregularities in the data or inconsistencies in logical thinking.

In the Classroom

In teaching for process using the field study as an instructional mode, the field studies should be planned which encompass a high level of student

involvement. This means that the studies should simulate a professional in the field. When problems have been raised which would best be studied in the field (e.g. pond life, ecological relationships, geological formations, etc.) students should be part of the planning, and the total sequence of preparatory work, in the field and back in the laboratory, should be insisted upon.

A General Outline for a Field Study of a Local Pond

I. Initiation

The students should be involved in making the preliminary arrangements. This should include such details as transportation, time schedules, first aid, finances, clothing, etc. Even if the trip is within the bounds of the school yard, it should be emphasized that these new activities are part of the professional in the field.

To achieve the greatest value, preliminary questions should be indentified. For beginning students, the field problems should be narrow in scope and involve a limited number of field techniques. Part of the design of the field problem and one which must be integrated into the learning experience is a knowledge of the tools and techniques necessary for the investigation. In biology, knowledge in the use of taxonomic keys, laying out transects for population studies, and methods of sampling, collecting, and preserving organisms, and gathering data, will be necessary.

Required background reading might be assigned and field trip techniques demonstrated before the trip is taken. If more than one problem is going to be

studied, assignment of responsibilities to individuals should be carried out.

II. Collection of Data

Field techniques might require further demonstration and, if specimens are collected, their preservation methods need to be considered. A log of all field activities in a field note book should be a part of the field experiences. Both the qualitative data and quantitative data should be designated. An outline of instructions and directions as to observations should be provided to pupils to increase their effectiveness. This is almost a must for any observations that can only be made in the field.

The teacher should visit the study site before the field trip to insure maximum utilization in terms of time, etc.

III. Processing the Data

This aspect would be developed upon return to the classroom. Data from field books would be organized, statistical analyses made and classifications carried out. Again, many special skills (preserving, mounting, classifying, etc.) have unlimited development as they apply to the discipline.

IV. Conceptualization of Data

Questions before the field study should be researched, and any additional questions should be answered and acted on by the class members. Relationships between the particular area and the background information should provide a useful insight into the particular area (useful if numerous trips are made to the same area by different classes and in different years).

In the follow-up, answers should be shared by all students and unusual

and unique instances described and discussed.

V. Open-endedness

The initial visit may provide opportunities for follow-up studies or new problems. In the study of pond life, seasonal variations may be part of the study, or a more detailed and comprehensive description of an area may be attempted.

H. SIMULATION

To vary the tempo of science instruction and provide avenues for process development, simulation as an instructional mode should be considered.

Definition of Instructional Mode

Simulation is defined by Wing as:

> . . . an imitation of real circumstances aimed at providing a learning environment; in other words, simulation is a technique by which the essential features of some object or process are abstracted and recombined in a model which represents the functions of the original and can be manipulated for the purpose of study or instruction.[44]

Rationale for its Use in Teaching for Process

Simulations are also referred to as games. In science these offer the students the opportunity to engage actively and imaginatively in the learning of abstract, scientific and increasingly technological concepts. Simulation is

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[44] R. L. Wing. "Simulation as a Method in Science Instruction," The Science Teacher, XXXV (5) (May, 1968), p. 41.

a valuable educational technique. Students of all ages can experiment with alternative strategies while engaging in a realistic and active learning environment. Students learn that conceptual and factual knowledge is not only valuable in its own right, but that it is more valuable when used as a tool for expanding knowledge. Students are able to apply what they know (substantive and the syntactical) to problem situations and make the decisions and evaluations by themselves. In a game situation there is total involvement which allows little time for intellectual withdrawal.

For the teachers, through simulations and/or games, many areas of science which are not otherwise demonstrable in the classroom (i.e. a field expedition to the northlands) may be included graphically and realistically. This method of presentation provides for a variety of classroom activity.

Teachers find that motivation and student interaction within the classroom are greatly improved. Students share ideas by working with others, and individual differences in ability are soon recognized by the pupils themselves.[45]

A Summary of Related Research

Research studies on simulation games are limited although a few studies provide some broad generalizations. Sanders[46] reports that junior high school

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[45] Refer to: Clark C. Alt and Virginia H. Cogger, "Educational Games for the Sciences, The Science Teacher, XXXVI (1) (Jan., 1969), pp. 36-39.

[46] Norris Sanders, "Changing Strategies of Instruction: Three Case Examples," in (ed.) Dorothy McClure Fraser, Social Studies Curriculum Development: Prospects and Problems, 39th Yr. Bk., National Council for the Social Studies (1968), p. 165.

students rated the simulation higher than did senior high students as a method of instruction. There was also some evidence that the simulations tested worked better with the more capable students. From reports, Sanders asserts that the new materials (simulation games) should fit fairly comfortably within the exisitng curriculum and classroom procedure, particularly since students tend to be passive learners and that simulation games may excite students about learning ... and ... help them to learn.

General Aspects of the Instructional Mode

The science game has its own pecularities, although the rationale behind games and the value of using them remains the same regardless of their subject matter.[47]

A. In the science game the element of competition is lacking, since scientists generally cooperate in an attempt to understand universal laws. It would seem that competition in science simulations is useful as a motivational factor.

B. In the science classroom, the student usually simulates the activity of a scientist. In terms of science processes, the students are given the opportunity to exhibit these in a cognitive manner.[48]

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[47] Refer to: Alt, ibid., pp. 36-37.

[48] See, Victor Showalter and Jane Stewart, Science Classroom in Orbit, The Science Teacher, 29 (6) (October, 1962), p. 42.

C. Science games can be used to expand the scope of knowledge in scientific areas of evolution, entropy, relativity, astronomical relationships and quantum mechanics. The winner in these games is the one who has the most complete understanding of nature. This approach may motivate the student to go much beyond the required materials of study. It should also be emphasized that content objectives may still be retained.

D. In simulation and games situations teaching objectives and the scope of the subject matter are delineated. Then the actors or decision makers and their objectives and resources are identified. The situation is then so structured that with the resources available, discovery of hidden subject matter and concepts is made possible. In the games situation, the interaction is sequenced and finally scoring rules and criteria for winning are formulated. In a simulation situation, a class discussion may be employed to evaluate and enhance individual situations.

Criteria for Use of Mode

The use of simulation as an instructional mode should be considered when the presentation of content is such that processes of science can be developed at a congitive level. Simulation should also be considered as a variation in teaching strategy and for motivational purposes. When maximum creativity is desired this mode can provide, with proper structure, many avenues for pupils to behave as scientists.

In the Classroom

It is difficult to perform some experiments in the classroom. The use of simulation as an instructional mode is one way of meeting the difficulty. Though the situations may be artificial, the student is part of the process and this aspect alone might enhance his learning experience. The following is an example of a simulation exercise by David J. Kuhn.[49]

> Simulate two woodland scenes: one, a spring scene in which the grass and trees are green; the other, an autumn-like scene in which the grass and trees are reddish-brown. The "survival" rate of "insects" of two different colors (red and green) may be tested in each environment. It is assumed that the colors of the insects are genetically determined.
>
> It is essential that the two scenes be identical except for the color. Artifical grass and plants can be purchased at variety and department stores. Several colors are normally available. If the materials of the desired color cannot be purchased, the materials can be painted the proper color with an aerosol spray paint. (The school art department may be able to construct these materials.)
>
> The woodland scene can be housed in any one of several containers - a standard glass terrarium, a cardboard box with the fourth side removed, or a wooden container. The ideal dimensions for the container would be: length 24 inches; width 12 inches; height 21 inches. In any case, the container should be three-sided and provide for easy access from the open side.
>
> A layer of humus placed in the base of the container will provide a natural base and be helpful in rooting any "plants" that are placed in the terrarium. The number, type, and arrangement of the plants should be similar in both of the woodland scenes.

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[49] David J. Kuhn, "A Simulation Game on Natural Selection," The Science Teacher, XXXVI (I) (January, 1969), p. 68.

The "insects" used in the exercise may be of various types. A good size for the insects is about 3/4 inch long and 3/8 inch wide. The insect type (e.g. beetles) can be cut out of stiff cardboard and painted either red or green using finger paints. Vac-u-form kits available at toy stores may also be used to make the "insects". The simplest approach is to represent the insects by using toothpicks of the proper colors. Twenty insects of each color should be provided for the experiment.

The students should work in pairs to perform the experiment. One student arranges the 40 beetles (20 red beetles, 20 green beetles) in the diarama; his partner can "prey upon" (remove) as many "insects" as possible in a 20-second interval. The same procedure should be repeated for the autumn scene. The number of insects "captured" for each color should be recorded for each environment.

The student should have the opportunity to develop his own model of the natural selection process through analysis and discussion of the data. Among the questions that can be raised are these: Which insect "survives" better in each environment? Are the differences in the number of insects captured in each environment slight, or are they significant? (A chi-square test may be used to test the significance of the differences between the number of insects surviving in each environment, but an "eyeball" analysis is usually sufficient.) Why do certain insects "survive" better than do others? How does the environment affect the "survival" of insects?

As a result of playing the "simulation game" the student should be able to develop the concept that the environment is a selective factor in evolution: At one time it may favor one variation; at another time, it will favor a different variation. This is the essence of the natural selection process. Hopefully, the student will emerge with some mental model of natural selection. His model may be inadequate at this point; it may have to be qualified or completely revised as the unit progresses. But, more important, the student has been involved in a basic process of science.

I. THE LECTURE AND DISCUSSION

The lecture and discussion as instructional modes involve "verbal" learning rather than physical activity. They can be distinct modes of instruction by themselves, but they inevitably are part of most other instructional activities.

Definition of Instructional Mode

A lecture is defined as an extended, formal discourse for the presentation of knowledge. In this instructional mode the teacher is "talking to" the class most of the time.

A discussion, in contrast to the lecture method, requires a greater degree of active participation on the part of the students.

In both, we will find the teacher encouraging questions on the part of students or asking questions himself. The lecture, largely because of its overuse, the low level of student interaction, and its undue emphasis on imparting factual knowledge, has lost much of its effectiveness as a means of developing inquiry. In the discussion, a "socratic" (dialectical) approach, an examination of alternatives, and "brainstorming" are possible to increase the level of inquiry. In the discussion the teacher plays more of a mediating role, whereas in the lecture he is more directive.

Rationale for its Use in Teaching for Process

The use of these two methods is necessary if some form of verbal interaction is to be achieved. The lecture can be used effectively in presenting

aspects of the scientific enterprise in terms of the processes for the presentation of an organized body of knowledge or for providing "clear-cut" comprehension of what the teacher thinks is important. A discussion provides for more "openness" and means for developing skills of critical thinking, for in the process dimension many opportunities exist for analyzing problems, research designs, etc., and for finding relationships and developing generalizations.

A Summary of Related Research

In discussing the lecture method versus the discussion method at the college level McKeachie summarizes the research in this field by stating:

> Despite the many findings of no significant differences in effectiveness between the lecture and discussion, those studies which have found differences make surprisingly good sense. In only two studies was one method superior to the other on a measure of knowledge of subject matter; both studies favoured the lecture method. In all six experiments finding significant differences favouring discussion over lecture, the measures were other (attitudes, interest, leadership, problem-solving) than final examinations testing knowledge.[50]

If it is possible to generalize the results of this research to the junior high level, it would seem that the discussion approach should be a major part of science instruction. If we are concerned with the total development of the child, this seems to be the direction one should follow.

General Aspects of the Instructional Mode

The effectiveness of either the lecture or discussion as a method will depend on the experiences of the teacher. Since the lecture invokes intellectual

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[50] Gage, op.cit.,p. 1127

rather than physical participation, it takes careful planning in the structuring of the lecture so that one may have attentive pupils in the classroom. Failure to do so results in bored, listless pupils who usually are a cause of discipline problems.

This is not to say that the lecture method is not worthwhile, for certain instruction can only be done in this manner. But, if used, the length or duration should not exceed the attention span of the pupils. To be particularly effective, several visual aids such as the chalkboard, overhead projector, models or other A.V. media apparatus could be used. The lecture presentation should probably be limited to a short description of a process, a statement of fact or a narration of a personal experience. Since the teaching process calls for a stimulation of the intellectual faculties in the pupil being taught, one-way dialogue should play a relatively minor role in instruction.

To develop greater interaction between teacher and pupil and pupils amongst pupils, the discussion method should be attempted. This method requires knowedge of group dynamics, mastery of asking and leading questions, and an understanding of how student inquiry can best be developed through discussions.

Since an objective of science instruction is to teach the processes of science, with emphasis on the cognitive development of the individual, students need to be provided with the time and the opportunities to develop these critical thinking skills. If it is this communicative aspect that we desire, the discussion approach has possibilities. A good discussion leader uses the

"What do you think?" approach to learning.[51] For process development, the questioning techniques used should develop critical thinking skills. In the course of discussion the following questions may be proposed:

1. What gave you an idea for this problem?
2. What did the data show?
3. Do you have sufficient data?
4. Are any improvements necessary in the design?
5. What led you to present this hypothesis?
6. How many variables are involved?

In this mode the ultimate success depends on the perceptions the teacher has in stimulating the student to think.

Questioning Techniques in Teaching for Process Through Inquiry

Since learning is a humanizing and socializing experience, the type and quality of questions presented to a student may guide the student's learning process to a considerable extent. Questioning starts a process of involvement and interaction central to the learning process. Though different inquiry modes may be used as variations in learning techniques, the interactions in the class that take place by way of discussions, responses, etc., associated with these learning techniques will have their initial development in questions and

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[51] Sund, op. cit., p. 131.

questioning. It could be said that questioning techniques are a significant factor in teaching for process through inquiry. The following factors are applicable not only to lectures and discussions, but to all aspects of instruction.

Questions may be used for different purposes:

1. To be part of a mental stimulus in the learning situations where a sustained answer is desired. These are the questions that are prefixed with "What," "Why," "How," and "Where."[52] Since science is in part a matter of asking questions and trying to find answers, many scientific questions can be reduced to such simple forms.

What is a natural community?

How do aquatic insects get air?

Where are the early stages of dragonflies found?

Why is chilling a necessary process for many plants?

2. To direct student conceptualization. This approach may be used in any process, but is best expressed by an example: that of helping a student through the process of observing.[53]

Approach Number 1

Student: Mr. Jones, I've been looking at this mineral specimen for ten minutes and I'm not sure. Is it Quartz?

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[52]Adapted from Brandwein, Paul F., Fletcher G. Watson, and Paul E. Blackwood, Teaching High School Science: A Book of Methods (New York: Harcourt, Brace, 1958), p. 131.

[53] Wm. D. Romey, Inquiry Techniques for Teaching Science (New Jersey: Prentice-Hall, 1968). p. 61.

Mr. Jones: Well, what do you think?

(Student throws mineral at Mr. Jones, and stamps out the room).

Approach Number 2.

Student: Mr. Jones, I've been looking at this mineral specimen for ten minutes and I'm not sure. Is it quartz?

Mr. Jones: Does it have clearage?

Student: Not that I can see.

Mr. Jones: How hard is it?

Student: Harder than this piece of glass.

Mr. Jones: According to your table, are those the properties you would expect to find in quartz?

Student: Gee, yes.

Mr. Jones: Do any other minerals on the chart seem to fit those properties?

Student: No. I guess it must be quartz. (Big smile.)

As noted above, to ask creative questions, they must be asked in a logical sequence and build towards a point of concept development. It should probably be said that skill in developing this type of logical sequence is of prime importance.

3. To provide levels of abstraction. This aspect provides for quality questions. In many of the processes higher mental capacities are required. Depending on the type of students present in the classrooms, the type of questions asked may challenge the pupils to more productive pursuits.

To classify the questions, Sander's[54] taxonomy of questions was used. The questions are structured along Bloom's Taxonomy of Educational Objectives.

Categories:

Memory

This type of question requires the student to recognize or recall information. The question is so framed that if the student remembers information presented to him he will know it applies to the question. These questions will usually be on knowledge associated with Generalizations, Values and Skills.

e.g. What are the characteristics of an Arctic biome?

Translation

This type of question requires the intellectual process of changing ideas in a communication into parallel forms. The ideas may be oral, written, pictorial, or graphic. The ideas are important and not the mechanics of translation.

Interpretation

With this type of question the student relates facts, generalizations, definitions, values and skills.

Six forms of relationships fall into this category.

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[54] Morris M. Sanders, Classroom Questions: What Kinds? (New York: Harper and Row, 1966).

1. Comparative relationship (Determining if ideas are identical, similar, different, unrelated, or contradictory).

2. Relationship of implication.

3. Relationship of an inductive generalization to supporting evidence.

4. Relationship of a value, skill or definition to an example of its use.

5. Numerical relationship.

6. Cause and effect relationship.

Situation: Students have collected the lengths of the middle finger. The values are recorded on the blackboard.

Questions: Interpretation (5).

1. Make a bar graph to show the distribution of finger lengths in the class.

What is the average middle finger length of your group? (5)

What do you think the curve of the graph would be if we plotted the middle finger lengths of all the grade sevens in the school? (2)

Application

These questions are designed to give students practice in the transfer of training.

1. Questions deal with knowledge which has explanatory or problem solving power.

2. Those that deal with the whole of ideas and skills rather than solely with parts.

3. Minimum of instructions - the student is expected to know what to do. After the pupils are familiar with the Processes in Science they may be required to undertake a complete research or project.

Analysis

This type of question shows a concern for subject matter and for the intellectual process involved in finding a solution.

Before this type of question is asked students should have some instruction on reasoning. In Junior High School Science classes development of the scientific method would be a process of reasoning.

Present situational aspects where the "scientific method" and process of science may be used to qualify the answers.

Synthesis

These questions encourage students to engage in imaginative, original thinking. These allow students great freedom in seeking solutions and students know there are many approaches. Most questions in previous categories limit students to subject matter and thought processes that are stated or implicit in the question, while restrictions of this type are kept to a minimum in the synthesis category.

e.g. How might a natural community become established on an island that has been newly formed by volcanic action?

Evaluation

Questions of evaluation are based on two criteria, that is how objects or ideas are expressed in:

1. the setting up of appropriate standards or values

2. determining how closely the idea or object meets these standards or values.

e.g. It is the intention of wildlife officials to introduce new species of wild life into the Edmonton area. If you were to choose between a polar bear, a camel and a yak which one would you suggest? Explain the basis of your decision.

CHAPTER V

A DESCRIPTION, ANALYSIS AND INTERPRETATION OF PROCESS APPROACH TEACHING BY FIVE TEACHERS

I. INTRODUCTION

The previous chapter presented strategies that may be used to teach the process dimension in science. With the aid of an instructional model and the philosophical tenets of Parker and Rubin with respect to curriculum building, behavioral objectives in the process domain were outlined and hypothetical lessons developed for numerous instructional modes. Underlying the approach to the problem of this study, "How to teach for the process of science?" were the cooperative efforts of the researcher, a colleague, and five teachers.

The teachers attempted to put into practice ideas, proposals, and methodologies that were the result of cooperative interactions among the researcher and the teachers. Through their efforts, the researcher obtained insights, information, and evaluations which made it possible to develop the instructional modes to their present format. By consciously attempting to teach for process and keeping records of this instruction, it was possible, perhaps for the first time, to assess some facets of the process approach teaching. It should be emphasized that this reporting extended for a major portion of the school year. This in itself provided data which is probably more meaningful than short term studies, for the patterns can be assumed to represent more closely classroom operations

as they really were. From this data strengths and weaknesses were noted which can provide the basis for further development.

The teachers in this study were designated as A, B, C, D, and E. In this description and analysis, the investigator is in no way making an evaluation of the individual teachers. Each teacher is regarded as exceptional in terms of ability to teach as compared to the total population of science teachers. The results are based on a select group of five teachers, each unique in his own way.

II. TEACHING FOR PROCESS

The Teachers and Their Schools

All the teachers in this study were junior high school teachers. No further teacher characterizations were made. Studies have shown that sex, age, years of training and other personal factors have had little significance on pupil achievement in the classroom.[1,2].

Some of the schools in which the teachers operated had modern facilities (i.e. "science islands" and trapezoidal desks for group work). Others were semi-

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[1] J. W. Getzels and P.W. Jackson, "The Teacher's Personality and Characteristics" Handbook of Research on Teaching, N.L. Gage (ed.), (Chicago: Rand McNally and Company, 1963), pp. 506-582.

[2] David G. Ryans "Research on Teacher Behavior in the Context of the Teacher Characteristics", Contemporary Research on Teacher Effectiveness, Bruce J. Biddle and William J. Ellena (ed.), (N.Y.: Holt, Rinehart and Winston, 1964), pp. 67-101.

traditional (i.e. demonstration table and flat top desks). Although the newer schools were better endowed in facilities and equipment the differences did not appear to hinder process teaching. This is not to say that facilities are not important, but that the teachers in this study had adapted to their particular situations.

As the researchers visited the schools, certain intuitive judgements were made to describe the teachers and their teaching. This study makes no attempt to ascertain what effect these have on the educative process. Such generalizations would involve the evaluative aspects and attempts to explain performance on the measures used for assessing the outcomes of process teaching.

An attempt was made to describe and rank the teachers on a number of attributes based on the intuitive judgments. For this purpose the literature was perused and attributes of good teachers and teaching listed. Reliability and validity judgement are not specifically considered, but these are the impressions which are held by the researcher and his colleague. It was through this list of factors that a description of the teachers was made. The teachers were ranked by each of the two observers. When both agreed at the extremes, the particular teacher was considered as carrying out a conforming function or a non-conforming function in terms of the intuitive perceptions as held by the researchers. When no agreement was reached the intuitve perception held for that teacher was ranked as "equal" in consideration to the other teachers. There was no explanation of the attributes beyond their identification. No comparative significance is attached to the description as this would result in evaluating the

teachers. Furthermore, the results of the companion study are needed to provide inferences in terms of evaluative outcomes as they may be related to the functions.

A Description of the Teachers Based on Intuitive Judgements: A Ranking on Different Attributes[3,4].

CONFORMING FUNCTION	EQUAL	NONCONFORMING FUNCTION
	1. Explaining, informing, showing how	
D	A, C, and E	B
	2. Initiating, directing, administering	
D	A, C, and E	B
	3. Unifying the group	
D A	C E	B
	4. Giving security	
D C	A E	B
	5. Clarifying attitudes, beliefs, problems	
D A	C and E	B
	6. Diagnosing learning problems	
D	A, C, and E	B

[3,4] Attributes based on: Louise E. Raths, "What is a Good Teacher?" pp. 8-14 and Marie M. Hughes and Associates, "The Model of Good Teaching," pp. 21-24, in James Raths, John R. Pancella and James S. VanNess, Studying Teaching (Englewood Cliffs, N. J.: prentice-Hall Inc.,), 1967.

CONFORMING FUNCTION		EQUAL		NONCONFORMING FUNCTION
		7. Making of curriculum materials.		
		B, C, D, and E		A
		8. Evaluating, recording, reporting		
D		A, B, C, and E		
		9. Organizing and arranging classroom		
C	D	E	B	A
		10. Rapport and interaction		
D	A	C	B	E
		11. Student respect for teacher		
		A, C, D, and E		B
		12. Teacher respect for students		
D		A and C	E	B
		13. Child open to his experience-individuality		
D		A and E	B	C
		14. Communicative skills		
D		A and C	E	B
		15. Responsive to the data the child and group are placing in the situation		
D	A	B, C, and E		
		16. Exercise of controlling functions		
		A, C, D and E		B

CONFORMING FUNCTION EQUAL NONCONFORMING FUNCTION

17. Supportive interpersonal relationships

D A, B, D, and E

18. The processes of science and the scientific enterprise

D A,B, and E C

Using the criteria consisting of a continuum of Conforming Function, Equal, and Nonconforming Function, the two observers agreed on 52.2% of the placements in terms of their intuitive judgements. They were in perfect agreement on all five teachers in 22.2% of the judgements, 22.2% agreement in placing three teachers, 27.8% when placing two teachers and 27.7% agreement when placing one teacher. When four teachers were correctly ranked the fifth naturally was correctly placed. This is the reason for no four teacher placement.

On the individual rankings, teacher C was perceived as carrying out a conforming function on the continuum 5.6% of the time, teacher D for 77%, and equal ratings were shared for 16.7% of the time. In terms of the perceptionsheld by the researchers, it would seem to indicate that teacher D was superior on the intuitive attributes as outlined in the study.

On the other end of the continuum, nonconforming function rankings were assigned to teacher A in 11.1% of the cases; teacher B in 55.6% of the cases; teacher C, 11.1%; teacher E, 5.6%, and equal ranking was shared in 16.7% of the time.

In terms of being ranked equal, teacher A was ranked 25.6% of the time in this category; teacher B, 11.6%; teacher C, 27.9%; teacher D, 7.2% and

teacher E, 27.9%. This would indicate that teachers A, C, and E rank somewhere in the middle of the continuum in terms of the intuitive judgements as perceived by the researchers.

Although the teachers were ranked and described in terms of specified intuitive judgements, two facets are noted: (1) that judgements about teachers are made and (2) it is difficult to get consensus in terms of a description.

Teaching Time

To provide some impression of the amount and distribution of time that teachers had for science instruction, Table III presents a comparison of the total teaching time reported to the total estimated time. The times that are provided are those which coincide with the formal reporting.

The estimated time is based on fourteen weeks of actual teaching time available for science instruction for the classes used in this research study. The total estimated time ranged from 2100 minutes in 42 lessons to 2800 minutes and 56 lessons. This invariably provided more time for science teaching for two teachers, C and D as compared with the time for teachers A, B and E. The type of instructional mode used as a result of the time factor could come under consideration. If the time is limited, more emphasis might be placed on the lecture and demonstration as compared to the laboratory and to discussion.

The variations that exist in the estimated times are accounted for by the different time schedules in the various schools. Four of the schools had fixed time tables, with either four periods of forty-three minutes per week, or three or four periods of fifty minutes. One school had a flexible modular schedule, making variation possible in the weekly pattern.

TABLE III

A COMPARISON OF TOTAL TEACHING TIME REPORTED TO TOTAL ESTIMATED TIME

Teacher	Reported		Estimated[a]	
	Lessons	Time (Min.)	Lessons	Time (Min.)
A	38	1840	46	2204
B	57	2280	56	2240
C	36	1850[b]	56	2800
D	44	2740	42	2520
E	45	2330	42	2100

[a] There were 16 weeks of classes. The estimated time is based on 14 weeks of actual classroom instruction, excluding time for evaluation for this study or teacher evaluation.

[b] There were no reports received for 4 weeks. Taking this into account would have yielded a reported time of 2650 minutes.

The reported time is based on the reports of the lessons as provided by the teachers. The lowest was teacher A with 1840 minutes in 38 lessons to 2740 minutes in 44 lessons for teacher D. Of the five teachers three reported more actual teaching time than the time estimated. This would indicate that the time provided for science teaching was actually available and the teacher had the responsibility of providing the instruction.

The differences that exist between the actual time and the time possible are probably due to a number of factors. These include the relative emphasis on formal teacher evaluation (tests). The occurrence or non-occurrence of school holidays or staff meetings on the days the classes were scheduled - this is especially disruptive if a double period exists on the same day. The amount of time spent in science instruction in the last two weeks before the Christmas recess affected instruction, since a few of the schools were affected by Christmas concert rehearsals, etc.

This study is not specifically evaluating any factor that may have a bearing on the success or lack of success in teaching for process. It does, however attempt to summarize the factors that were in existence. The reader is referred to the doctoral dissertation being prepared by J.A. MacDonald for information regarding the formal evaluative aspects of this research project.

The Instructional Modes

The amount of time spent in the different instructional modes as reported by the teachers is summarized in Table IV. The different amounts of time spent in the variety of instructional modes may be attributed to differences

in teaching styles. As a result, the pupils of different teachers were involved differently in the teaching for the processes of science.

From the data in Table IV it is noted that the teachers employed the laboratory mode for approximately 35% of the time, with the exception of teacher B, who used it less than 2%. The discussion instruction mode followed next with an average of approximately 20%, with teacher B high at 25% and teacher D low at 13%. The use of the lecture was more diversified with teacher A and B using it for 7% of the time and D and E approximately 21%. Teacher C was at the 1% level. A.V. media was extensively used by some teachers, namely B, C and E who used this mode for approximately 20%. Teacher A employed this mode for 2.7% and no record of its use is made by teacher D. Teacher D used the demonstration mode for approximately 15% of the time in comparison to the other four teachers who averaged approximately 2%. The use of the field study is reported by two teachers, C and D; history of science, by teacher E; invitations to inquiry, by teacher B; simulations, by all except E; project, by B and D; and library research, by teachers A and B. These latter modes account for less than 3% of the time. The "other" instructional mode was used by all teachers with the exception of E. Teachers A, B and D averaged 9% and teacher C accounts approximately 29% in this mode. In this study four instructional modes accounted for most of the teaching style. These were: (approximation) the laboratory 35%, use of A.V. media 20%, lecture and discussion 35% and "other", 10%.

TABLE IV

THE PERCENTAGE OF TIME SPENT USING DIFFERENT INSTRUCTIONAL MODES AS REPORTED BY THE TEACHERS

Teacher	INSTRUCTIONAL MODES											
	Laboratory	Demonstration	A-V Media	Field Study	History of Science	Invitations to Inquiry	Simulations	Project	Library Research	Lecture	Discussion	Other
Total min.												
A (1840)	40.1	0.0	2.7	9.5	0.0	0.0	2.7	0.0	7.5	6.9	23.9	6.8
B (2280)	1.8	3.7	23.2	3.5	0.0	9.2	8.6	0.9	12.1	6.8	25.0	5.3
C (1850)	32.3	5.0	14.8	0.0	0.0	0.0	1.4	0.0	0.0	1.2	18.7	29.4
D (2740)	33.8	14.5	0.0	0.0	0.0	0.0	0.6	0.0	0.0	21.5	12.9	14.9
E (2330)	36.3	0.0	21.6	4.7	2.1	0.0	0.0	6.9	0.0	20.4	17.6	0.0

Other: Includes written work, reviews, library study, chart making, model study, blackboard notes, specimen study, etc.

The "other" included written work, blackboard notes, chart making, model study, etc. Some of these are part of the specific instructional modes considered. Perhaps these could be incorporated as part of some of the outlined modes. For example, written work and blackboard notes could be part of any mode. Reviews and drills are part of good teaching, and perhaps are a category by themselves. In this study, it was felt that too much time was spent on reviewing by some of the teachers.

Several other observations may be made from the data in Table IV. No one teacher varied his teaching by using all the instructional modes and every instructional mode was used by some of the teachers. It should be noted that for some teachers a different interpretation is placed on a mode when compared to that envisioned by the researcher. In the instances of simulation, history of science, demonstration and field study, these modes were part of specific processes, i.e. history of science was used for "background information" and simulation was interpreted as "doing as a scientist" with regard to graphing, recording, etc. Library research for the teachers was a separate instructional mode which, for purposes of this study, became part of the project. The question arose whether or not the library research was part of the "background information" of some other instructional mode, or whether it was a separate instructional mode which resulted in finding the solution to a problem through work in the library.

The amount of time for preparation and the resources available could be a factor in the use of some modes as outlined in this research. History of

science, invitations to inquiry, simulations, and even demonstrations (silent) require much pre-planning. The use of the field study could depend on suitable areas close enough to the school to be utilized. In the use of A.V. media, availability of inquiry oriented media becomes a factor.

Some teachers spent more time in lecture in proportion to discussion in comparison to the other teachers. This raises the possibility that the lecture may have been recorded as part of different instructional modes.

Furthermore, it is possible that all instructional modes did not lend themselves to process teaching because the substantive material in some areas of the grade seven life science course could get better treatment in terms of the scientific enterprise in some other mode.

The use of simulation as an instructional mode needs further clarification. To the teacher who reported its use, simulation implied the pupil working as a scientist in the classroom. In the total context this may be so, but simulation can also be used for more specific cases, such as contriving situations of natural phenomena for study in a classroom setting, i.e. a study of the problems associated with the lemming migration in the Scandinavian countries.

The Teaching for Process

Table V presents the distribution by teacher of processes taught within the different instructional modes. The involvement of students in the processes is proportionate to the time spent in the instructional mode. The breakdown per teacher in which the major portion of the processes was taught within specific instructional modes is as follows: teacher A, (approximate values), laboratory

TABLE V

THE PERCENTAGE OF THE TOTAL PROCESSES TAUGHT WITHIN THE DIFFERENT INSTRUCTIONAL MODES

Teacher	INSTRUCTIONAL MODES												
	Laboratory	Demonstration	A-V Media	Field Study	History of Science	Invitations to Inquiry	Simulations	Project	Library Research	Lecture	Discussion	Other	Double Count
Total													
A (148)	41.9	0.0	1.4	5.4	0.0	0.0	6.8	0.0	5.4	14.2	25.0	1.9	48.7
B (240)	0.4	2.5	28.8	0.4	0.0	7.5	9.2	2.5	6.8	5.0	37.1	2.5	37.9
C (351)	24.5	9.7	14.2	0.0	0.0	0.0	3.7	0.0	0.0	3.1	35.0	9.7	43.0
D (253)	27.7	13.8	0.0	0.0	0.0	0.0	0.4	0.0	0.0	21.7	20.6	15.8	53.1
E (240)	27.5	0.0	22.5	5.0	0.4	0.0	0.0	1.2	0.0	18.3	25.0	0.0	54.6

* When a teacher used two or more instructional modes within a teaching period, the process was not assigned to one particular instructional mode, but was distributed for all the instructional modes indicated. On a tabulation sheet the process(es) was assigned to an instructional mode. Using a different marking, this same process was assigned to all other instructional modes that were used. Nevertheless patterns emerge and this "double count" does give an assessment as to how the processes were distributed in terms of the instructional modes.

42%, lecture 14%, and discussion 25%; teacher B, A-V media 29%, simulation 9% and discussion 37%; teacher C, laboratory 25%, demonstration 10%, A-V media 14%, and discussion 35%; teacher D, Laboratory 28%, demonstrations 14%, lecture 22% and discussion 21%; and teacher E, laboratory 28%, A-V media 23%, lecture 18% and discussion 25%. It can be generalized that 85% of the processes were taught within five instructional modes - laboratory, lecture, discussion, A-V media and demonstration. Even within these five, substantial differences existed. Teacher B recorded .4 % on laboratory and 5% on lecture, teachers A and D recorded 1.4% and 0.0% respectively in the use of A-V media, and teacher C only 3.1% on lecture. The teaching of processes within the five instructional modes is to be expected. These are the traditional instructional modes that have received the most emphasis in science instruction.

A detailed breakdown of the processes taught by the different teachers in the different instructional modes is shown in Table VI. This provides a better indication of the amount of involvement in the teaching for process in terms of each specific process in an instructional mode. The laboratory instructional mode was used mainly for the processes (approximate values): procedure 15%, observations and observing 20%, organizing data 10%, and interpreting data 15%. The lecture was used mainly for (approximate values): identifying problems 10%, background information 15%, hypothesis 10%, design of experiment 15%, and interpreting data 15%. The discussion mode had greater diversification among the teachers, but the same processes that were developed under the lecture mode, had their greatest emphasis here. Teachers

B and E who used the A-V media extensively used it mainly for developing the following processes (approximations): identifying problems 6%, background information 23%, hypothesis 6%, observing and observations 13%, and organizing data 15%. This does indicate that processes may be taught within all instructional modes proposed. It also follows that some processes are developed more successfully in some instructional modes, i.e. A-V media for background information, lecture for hypothesis and discussion for observations and observing, and interpreting data.

Furthermore, the teachers spent more time on the processes in the upper half of the inventory as compared with those in the lower half. Several reasons for this may be advanced. Since grade seven students are introduced to this inventory for the first time, it seems natural that more time would be spent on the Initiation and Collection for Data stages of the inventory. Moreover, the concepts of "introduction to science", classification and variation generally did not lend themselves to the latter aspects of the inventory: Conceptualization of Data (operational definitions, mathematical relationships, and mental models) and Open-endedness. It should be stressed that it takes time to prepare the students to operationalize the steps of the inventory in terms of understanding what is involved in each process and the nature of the inventory as it relates to the scientific enterprise. Furthermore, teachers being conscious of the time element, resources, space, etc. may find it difficult to organize the work to proceed in an unstructured manner. It is also doubtful whether students at this early stage would be able to pursue this type of work. However, it is disturbing

to note that this formal and structured activity continued throughout the study. Probably the optimum of this individualized approach would have been project work. However, during this study very little instruction was done in this manner.

It is again noticed that many instructional modes are used to impart only specific processes, e.g. A-V media for "background information" or "observations of phenomena". These usually become part of the laboratory instructional mode. This would indicate that the teachers have found it difficult to incorporate the processes of the scientific enterprises in an instructional mode other than the laboratory mode. This also leads one to suspect that most instructional materials are prepared for the laboratory mode, and with pressures of time, the instrucational materials most readily available are used. Through discussions the teachers have indicated that a history of science approach, or a silent demonstration or a simulati on is adaptable to process approach teaching, but requires a great amount of preparatory time. Furthermore, in the A-V media instructional mode, few "raw data" or inquiry structured sources of materials are available. Thus, teachers use these in development of specific processes, i.e. observation or interpretation.

Several other facets in the teaching for process are noted. Doubts emerge regarding the comprehension the teachers have of "What is Science?" and their understanding of the scientific enterprise. Although it could be argued that there are as many methods as there are scientists, it is the contention that teachers have a dual responsibility. One is to impart the substantive aspects of

TABLE VI

THE PERCENTAGE OF SPECIFIC COMPONENT PROCESSES TAUGHT WITHIN THE INSTRUCTIONAL MODES

Teacher	INSTRUCTIONAL MODES											
	Laboratory	Demonstration	A-V Media	Field Study	History of Science	Invitations to Inquiry	Simulations	Project	Library Research	Lecture	Discussion	Other
	1. Identifying Problems											
A	1.6	--	--	--	--	--	--	--	--	4.8	5.4	2.7
B	--	16.7	7.2	--	--	22.2	9.1	16.7	31.3	8.3	9.0	16.7
C	2.3	2.9	--	--	--	--	15.4	--	--	9.1	0.8	--
D	7.1	25.7	--	--	--	--	100.0	--	--	21.8	17.3	20.0
E	6.1	--	5.6	8.3	--	--	--	33.3	--	6.8	6.7	--
	2. Background Information											
A	1.6	--	100.0	--	--	--	--	--	12.5	9.5	13.5	--
B	--	16.7	23.2	--	--	11.1	9.1	50.0	43.8	16.7	25.8	33.3
C	9.3	5.9	12.0	--	--	--	7.7	--	--	--	7.3	17.6
D	2.9	14.0	--	--	--	--	--	--	--	12.7	11.5	12.5
E	15.2	--	22.2	8.3	100.0	--	--	66.7	--	20.4	21.7	--

TABLE VI (Continued)

Teacher	Lab.	Demon.	A-V	Field St.	Hist. of Sc.	Inv. to Iq.	Simuln's.	Project	Lib. R.	Lecture	Discussion	Other
	INSTRUCTIONAL MODES											
	3. Predictions											
A	8.1	--	--	--	--	--	20.0	--	--	--	5.4	--
B	--	33.3	4.3	--	--	22.2	18.2	--	--	33.3	5.6	--
C	12.8	11.8	14.0	--	--	--	15.4	--	--	9.1	16.3	11.8
D	--	--	--	--	--	--	--	--	--	1.8	--	--
E	1.5	--	--	--	--	--	--	--	--	2.3	1.7	--
	4. Hypothesis											
A	1.6	--	--	--	--	--	--	--	12.5	9.5	8.1	--
B	--	--	4.3	--	--	11.1	9.1	--	--	16.7	3.4	--
C	9.3	8.8	12.0	--	--	--	15.4	--	--	18.2	10.2	8.8
D	2.9	--	--	--	--	--	--	--	--	7.3	5.8	10.0
E	4.6	--	7.4	--	--	--	--	--	--	6.8	5.0	--
	5. Design of Experiment											
A	6.4	--	--	--	--	--	20.0	--	--	9.5	5.4	--
B	--	--	--	--	--	--	--	--	--	16.7	--	--
C	2.3	8.8	4.0	--	--	--	--	--	--	--	2.4	--
D	10.0	17.1	--	--	--	--	--	--	--	20.0	17.3	12.5
E	7.6	--	7.4	25.0	--	--	--	--	--	6.8	6.7	--

TABLE VI (Continued)

Teacher	INSTRUCTIONAL MODES											
	Lab.	Demon.	A-V	Field St.	Hist. of Sc.	Inv. to Iq.	Simuln's.	Project	Lib. R.	Lecture	Discussion	Other
	6. Procedure											
A	6.4	--	--	50.0	--	--	20.0	--	--	4.8	5.4	--
B	--	--	--	--	--	--	--	--	--	--	--	--
C	14.9	11.8	16.0	--	--	--	15.4	--	--	9.1	13.0	14.7
D	14.3	5.7	--	--	--	--	--	--	--	3.6	5.7	5.0
E	13.6	--	13.0	16.7	--	--	--	--	--	11.4	11.7	--
	7. Observations and Observing											
A	25.8	--	--	50.0	--	--	20.0	--	--	4.8	10.8	--
B	--	--	13.0	100.0	--	11.1	--	33.3	--	--	12.4	--
C	15.1	11.8	16.0	--	--	--	7.7	--	--	9.1	16.3	26.5
D	20.0	17.1	--	--	--	--	--	--	--	12.7	23.1	10.0
E	15.2	--	13.0	16.7	--	--	--	--	--	13.6	11.7	--
	8. Organizing Data											
A	25.8	--	--	--	--	--	10.0	--	--	9.5	8.1	--
B	--	--	17.4	--	--	--	9.1	--	12.5	--	14.6	50.0
C	4.6	5.9	4.0	--	--	--	--	--	--	--	2.4	--
D	10.0	2.9	--	--	--	--	--	--	--	1.8	1.9	5.0
E	16.8	--	11.1	--	--	--	--	--	--	18.8	15.0	--

TABLE VI (Continued)

Teacher	Lab.	Demon.	A-V	Field St.	Hist. of Sc.	Inv. to Iq.	Simuln's.	Project	Lib. R.	Lecture	Discussion	Other
	INSTRUCTIONAL MODES											
	9. Representing Data Graphically											
A	3.2	--	--	--	--	--	--	--	--	9.5	5.4	--
B	--	33.3	1.4	--	--	11.1	54.5	--	--	--	2.3	--
C	3.5	8.8	6.0	--	--	--	--	--	--	--	1.6	--
D	--	5.7	--	--	--	--	--	--	--	1.8	1.9	5.0
E	3.0	3.7	--	--	--	--	--	--	--	--	3.3	--
	10. Mathematical Treatment											
A	1.6	--	--	--	--	--	10.0	--	--	--	--	--
B	--	--	--	--	--	--	9.1	--	--	--	1.1	--
C	1.2	2.9	2.0	--	--	--	--	--	--	--	0.8	--
D	--	2.9	--	--	--	--	--	--	--	--	--	5.0
E	--	--	--	--	--	--	--	--	--	--	--	--
	11. Interpreting of Data											
A	--	--	--	--	--	--	--	--	37.5	9.5	13.5	--
B	100.0	--	13.0	--	--	11.1	9.1	--	12.5	8.3	14.6	--
C	17.4	11.8	12.0	--	--	--	7.7	--	--	18.2	19.5	20.6
D	18.6	2.9	--	--	--	--	--	--	--	10.9	9.6	12.5
E	3.0	--	1.9	--	--	--	--	--	--	2.3	3.3	--

TABLE VI (Continued)

Teacher	Lab.	Demon.	A-V	Field St.	Hist. of Sc.	Inv. to Iq.	Simuln's.	Project	Lib. R.	Lecture	Discussion	Other
	INSTRUCTIONAL MODES											
	12. Operational Definitions											
A	--	--	--	--	--	--	--	--	37.5	--	8.1	--
B	--	--	--	--	--	--	--	--	--	--	--	--
C	2.3	5.9	--	--	--	--	15.4	--	--	9.1	3.2	--
D	4.3	--	--	--	--	--	--	--	--	--	--	--
E	3.0	--	1.9	--	--	--	--	--	--	--	3.3	--
	13. Mathematical Relationships											
A	--	--	--	--	--	--	--	--	--	--	--	--
B	--	--	--	--	--	--	9.1	--	--	--	1.1	--
C	--	--	--	--	--	--	--	--	--	--	--	--
D	--	--	--	--	--	--	--	--	--	--	--	--
E	--	--	--	--	--	--	--	--	--	--	--	--
	14. Mental Models											
A	--	---	--	--	--	--	--	--	--	--	--	--
B	--	--	--	--	--	--	--	--	--	--	--	--
C	1.2	--	--	--	--	--	--	--	--	--	0.8	--
D	--	--	--	--	--	--	--	--	--	--	--	--
E	--	--	--	--	--	--	--	--	--	--	--	--

TABLE VI (Continued)

Teacher	Lab.	Demon.	A-V	Field St.	Hist. of Sc.	Inv. to Iq.	Simuln's.	Project	Lib. R.	Lecture	Discussion	Other
	15. Further Evidence											
A	3.2	--	--	--	--	--	--	--	--	9.5	5.4	--
B	--	--	11.5	--	--	--	--	--	--	--	8.9	--
C	--	--	--	--	--	--	--	--	--	--	--	--
D	2.9	2.9	--	--	--	--	--	--	--	1.8	1.9	2.5
E	--	--	1.8	--	--	--	--	--	--	--	--	--
	16. New Problems											
A	--	--	--	--	--	--	--	--	--	--	--	--
B	--	--	--	--	--	--	--	--	--	--	--	--
C	6.9	2.9	2.0	--	--	--	--	--	--	18.2	4.9	--
D	5.7	2.9	--	--	--	--	--	--	--	1.8	3.8	2.5
E	4.6	--	3.7	8.3	--	--	--	--	--	4.5	5.0	--
	17. Application											
A	12.9	--	--	--	--	--	--	--	--	9.5	5.4	--
B	--	--	4.3	--	--	--	--	--	--	--	1.1	--
C	--	--	--	--	--	--	--	--	--	--	--	--
D	1.4	--	--	--	--	--	--	--	--	1.8	--	--
E	4.6	--	7.4	--	--	--	--	--	--	2.3	5.0	--
	Totals (N)											
A	62	--	2	8	--	--	10	--	8	21	37	3
B	1	12	69	1	--	18	22	6	16	12	89	6
C	86	34	50	--	--	--	13	--	--	11	123	34
D	70	35	--	--	--	--	1	--	--	55	52	40
E	66	--	54	12	1	--	--	3	--	44	60	--

science; the other is to portray as well as possible the syntactical aspects of science to their students.

If a concept was developed through statement of a problem, this would naturally lead on to background information, hypothesis, design, and so forth, and to the development of a new problem. In many cases this progression is not evident. There could be several reasons for this. First, the substantive material is not conceptually regarded as following a progressive pattern. Second, there probably is no one way of understanding the nature of the methods of the scientific enterprise. It could be emphasized that if this is not the way a scientist operates, it would seem that presenting material in a structured and logical format is part of good teaching. Two illustrations may be noted: Teacher B spent 0.4% of the process activity in the laboratory mode. Specifically, this was for interpreting data. The question arises, how did this stage evolve? As another example, teacher A spent 5.4% of the time in field studies, involving only procedure and observations. Surely, if a lesson is complete, there was or should have been pre-field study involvement of pupils. Numerous other examples may be noted to develop this point.

When reading the details provided within the teacher reports, the specific process - Procedure - had the most misconceptions in terms of understanding. It was used to outline the steps that were to be carried out in the investigation. This is interpreted as part of "design" in the use of the laboratory. Procedure is to be applied to any additional changes in design as the investigation (experiment) proceeds. This would suggest that more inservice with the teachers

in making use of the "An Inventory of Processes in Scientific Inquiry" is necessary.

Table VII shows the percentage of the total processes spent in each major process category by each teacher. Considering each teacher separately in terms of which processes he emphasized most, teacher A spent (approximately) 17% in organizing data, 18% in observation and observing and 9% in procedure. Teacher B spent 12% in identifying problems, 24% in background information, 11% in predicting, 10% in observing and observations, 13% in organizing data, and 12% in interpreting data. Teacher C worked mainly with predictions 14%, hypothesis 11%, procedure 13%, observations and observing 16%, interpreting of data 17% and new problems 16%. Teacher D spent 17% of the time in identifying problems, 10% in background information, 15% in the design of the experiment, 17% in oberserving and observations and 12% in interpreting of data. Teacher E devoted his teaching to background information 20%, design 8%, procedure 13%, observing and observations 13%, and organizing data 15%. In generalizing, the teachers emphasized the following processes: identifying problems, background information, predictions, hypotheses, design of experiment, procedure, observing and observations and interpreting data.

The tabulation of the processes in this table points out again the fact that processes in the upper half received more attention than those in the lower half. Possible reasons have already been suggested. The result may perhaps be interpreted as providing justification for the AAAS approach, Science- A Process Approach, in which "basic processes are developed before the more sophisticated procedures required in the "integrated processes" are encountered. The trends in

TABLE VII

PERCENTAGE OF TOTAL PROCESSES SPENT IN EACH MAJOR PROCESS CATEGORY BY EACH TEACHER

PROCESS	TEACHERS				
	A	B	C	D	E
1. Identifying Problems	2.7	11.7	1.9	17.4	6.7
2. Background Information	7.4	24.2	9.1	9.9	20.0
3. Predictions	6.1	10.8	13.9	0.4	1.2
4. Hypothesis	4.7	4.6	10.5	5.1	5.4
5. Design of Experiment	6.8	0.8	2.8	15.0	7.9
6. Procedure	8.8	0.0	13.1	7.5	12.5
7. Observation and Observing	18.2	10.4	15.9	17.0	13.3
8. Organizing Data	16.9	13.3	3.1	4.7	15.0

TABLE VII (Continued)

PROCESS	TEACHERS				
	A	B	C	D	E
9. Representing Data Graphically	4.0	5.4	3.1	2.4	3.3
10. Mathematical Treatment	1.4	1.2	1.1	0.8	0.0
11. Interpreting of Data	6.8	15.1	16.8	11.9	2.5
12. Operational Definitions	4.0	0.0	3.1	1.2	2.1
13. Mathematical Relationships	0.0	1.2	0.0	0.0	0.0
14. Mental Models	0.0	0.0	0.6	0.0	0.0
15. Further Evidence	4.0	6.7	0.0	2.4	0.4
16. New Problems	0.0	0.0	16.0	3.6	4.6
17. Application	8.1	1.7	0.0	2.8	5.0

Table VII may provide curriculum workers with some insights in developing process approach curricula. In structuring lessons, attempts could be made in introducing and utilizing all the seventeen processes over a period of time. It should be emphasized that many of the major processes incorporate a number of minor processes. When a major process is missed, the minor ones (forty-two) are probably not even considered. As an illustration, Organizing Data can involve: (a) ordering to identify regularities, (b) classifying and (c) comparing. Thus, lessons could be structured that will include as many of the processes as possible. Furthermore, to accommodate the syntactical dimension (process), it may be possible that the substantive elements in a course may be rearranged to provide for more process involvement.

From the data on Table VII, it appears that students need to be provided greater opportunities in terms of the pre-operations as well as post-operations in their learning experiences. The process of designing an experiment, a creative endeavor, could be provided with more time for development. Likewise, the processes further evidence (approximate averages) 3%, new problems 4%, and application 4% should receive more emphasis. It is in the area of Open-endedness that the whole process pattern can be repeated, and the activities brought closer to pupil interests. Operational definitions, (approximate averages) 3% and mathematical treatment 1% are also low, but considering the content covered during the period of the study, only a few lessons lent themselves to this treatment. The process of incorporating the new discovery into the existing theory "mental model" was given little attention. This process involves incorporating the

new discovery into existing theory. It is felt that if the substantive is structured, concepts would build upon concepts. Therefore, the student in this process should be developing a framework to the structures that exist in the discipline, in this instance, Life Science. As a result, knowledge of time spent in the various processes could have considerable implication in the way that the conceptual frameworks for the disciplines may be structured. More attention may be devoted to logical patterns as they relate to the structure, the substance and the syntax of a discipline. This may have a bearing on the approaches to a discipline as well as the approaches to teaching.

A Discussion of a Sample Lesson

The general format used by the teachers in structuring their investigative lessons is displayed by figure four. This style of format was used throughout the study. The intention was that the pupil would thus be involved more actively than by reading an investigation and performing it under teacher guidance.

In this sample lesson, a higher level of inquiry could probably have been achieved by even greater pupil involvement. The pupils could have been asked to state the problem after the teacher outlined the situation. This could have led to the background information, again to be carried out by the pupils. Finally, a hypothesis could have been required and the pupils requested to design procedures for the collection of data. The other steps could follow this developmental sequence.

It should be emphasized that such a structured format is necessary at the early stages of process approach teaching. In this study, the above structured

FIGURE 4

INVESTIGATION M-2 (SAMPLE)

GRADE 7

PROBLEM: To find out what happens when yeast and sugar solutions are mixed together and warmed.

BACKGROUND INFORMATION:

1. Refer to the New Problems in Investigation M-1 and summarize your answers.

2. By class discussion attempt to explain what an experimental control is, and what experimental variables are.

DESIGN FOR COLLECTION OF DATA:

1. Add about 1" to 1 1/2" of yeast and sugar solution to two test tubes. Label these test tubes A and B.

2. Place balloons over the mouth of these two test tubes, and put them in the rack.

3. Add about 1" to 1 1/2" of yeast solution to another test tube. Label this test tube C.

4. Place a balloon over the mouth of the test tube and place the tube in the rack.

5. Add about 1" to 1 1/2" of sugar solution in a test tube and label it D.

6. Put a balloon over the mouth of the test tube and put it in the rack.

7. Record the room temperature.

8. Observe what is happening to the solution and to the balloon for each test tube.

9. Place test tubes A, C and D in warm water. (Follow Instructions given in class).

10. Let the apparatus stand for about 15 minutes and then observe what is happening to the solution and the balloon for each test tube.

11. Record the temperature of the water after the 15 minutes.

MATERIALS: 4 test tubes, 4 balloons, centigrade thermometer, beaker (400 ml size), yeast solution, sugar solution.

NOTE: BEFORE YOU BEING CARRYING OUT THE DESIGN, YOU WILL RECORD ALL YOUR DATA IN A CHART SIMILAR TO THE ONE UNDER THE HEADING OBSERVATION.

FIGURE 4 (Continued)

PROCEDURE: Record any changes made to the design above.

OBSERVATIONS AND ORGANIZATION OF DATA:

Develop a chart that will help you record your data in a meaningful way. Follow instructions given.

INTERPRETATION OF DATA:

1. What has happened in test tube A and why?
2. What test tube has acted as a control for the experiment?
3. What effect does heating the yeast and sugar solution have on its behavior?
4. What experimental controls have you used in this experiment?

NEW PROBLEMS:

1. What kind of gas is formed by the yeast?
2. How could you test for this gas?

APPLICATION AND KNOWLEDGE:

How is the behavior of yeast (as observed in this investigation) useful in the baking industry?

format was used extensively throughout the study. Although many arguments can be presented for the use of this type of format, it is still the contention that the student should share in what may be the more creative aspects in his scientific development, such as stating a hypothesis and following this through with an "experiment". Here the student would be required to design an approach for the collection of data and within limitations (safety, resources, etc.) try to gather his data, make inferences, etc. Although, this is time consuming, the training, frustrations, and successes may probably have greater educational value and potential when compared to a teacher structured, "do this," "answer this" approach.

III THE FORMAL OBSERVATION

Three direct observations were made in this study of the behavior of the teachers while they were teaching and pupils while they were learning. The purpose of the visits was to obtain information as objectively as possible for assessing the reliability of teacher reports.

The observations were based on a structured observational instrument. (appendix C). This instrument attempts to determine the processes taught and some of the characteristics of the teaching. The rationale for the development of the instrument is described in Chapter III. Agreement on Part I of the instrument on the seventeen major process categories between the two observers was 100 per cent. Table VIII under the heading of criterion, shows the processes observed by the observers for each of the teachers.

Although there was perfect agreement on the major categories, it was

TABLE VIII

TEACHER PERCEPTION OF PROCESSES TAUGHT COMPARED TO THE CRITERION

THE FORMAL OBSERVATION

Processes	Teacher A	Criter-ion	Teacher B	Criter-ion	Teacher C	Criter-ion	Teacher D	Criter-ion	Teacher E	Criter-ion
	LESSONS									
	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3	1 2 3
Indentifying Problems		*	* *		* *		* * *	× × ×		*
Background Information	* *	× ×	* * *	× × ×	* * *	×	* *	* ×	* * *	× × ×
Predictions					* * *					
Hypothesis	* *	× × *			* * *	×				
Design of Experiment		* *					* * *	× ×		×
Procedure	* *	× ×			*		* * *	× ×	* * *	× ×
Observation	* * *	×	*	* ×	* * *	× × ×	* *	* × ×	* * *	× × ×

× Agreement - Teacher and Criterion

TABLE VIII (Continued)

Processes	Teacher A			Criterion			Teacher B			Criterion			Teacher C			Criterion			Teacher D			Criterion			Teacher E			Criterion		
	LESSONS																													
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Organizing Data	*		*								*		*			x									*			x		
Representing Data Graphically																														*
Math Treatment																									*		*		x	x
Interpreting of Data			*		x								*	*	*	x	x	x					*							
Operational Definitions														*	*															
Math Relationship																														
Mental Model																														
Further Evidence														*																
New Problems														*	*															
Application																														

x Agreement - Teacher and Criterion

felt that agreement on the basis of the sub-categories should be considered. To obtain a measure of discrepancy (association), a Chi Square test was performed. In applying this test a comparison was made of the observed frequencies with theoretical frequencies.

This calculation considered all the observations in the sub-categories in both Part 1, the process and Part 11, the characteristics of teaching.

The formula [5] for the test is stated in terms of χ^2. χ^2 is defined as:

$$\chi^2 = \frac{\Sigma (O - E)^2}{E}$$

where O is the observed and E the expected cell frequency.

The value of Chi Square at the $p < .05$ level of significance was selected as warranting the rejection of the null hypothesis that no difference exists between the observed and expected values.

In the test of significance of the null hypothesis that no differences exist between the observed and expected values, the χ^2 values for Part I and Part II are below the critical values at the .05 level (Table IX). Therefore, the null hypothesis is accepted at this level of significance.

It is inferred that the observations made by the two observers are correlated and in agreement. It is further inferred that the observational instrument was interpreted with a reasonable degree of reliability in recording the teachers'

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[5] George A. Ferguson, Statistical Analysis in Psychology and Education, (New York: McGraw Hill) 1966, pp. 200-201.

perceptions of the processes and the characteristics of their teaching.

TABLE IX

DETERMINED χ^2

Observation Instrument	df	χ^2	Critical Value $p < .05$
Part I	9	.716	16.92
Part II	20	9.069	31.41

This agreed process inventory between the two observers became the criterion, in terms of the major processes, by which each individual teacher was considered. For each lesson taught, the teacher marked off those major process categories he felt were translated to the student. It was agreed that if these were translated to the students by conscious teaching acts, the should be recognized by the observers.

The Wilcoxon Matched - Pairs Signed Ranks Test[6] was applied to test whether there were differences in the interpretations of the major processes of all the teachers against the criterion. The test was considered suitable because of the nominal nature of the variables, and the different teachers and different

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[6] Siegel, Op. cit. pp. 75-83.

teaching situations that existed. This test is able to provide information to make judgements based on data in which the direction and magnitude of the differences within pairs are considered. Table X presents the data for this test.

In terms of Wilcoxon test, H_o: the perceptions, interpretations and understanding of the processes as held by the teachers do not differ from the criterion, was tested. If the observed value of T is equal to or less than the critical value for a particular significance level and a particular N, H_o may be rejected at that level of significance. From Table X, T = 10.5 for N = 12, allows us to reject the null hypothesis at the .05 level of significance, in favor of the fact that at this level of significance the teachers interpretations of the processes do differ statistically significantly from that of the criterion set.

Since differences did appear at the .05 level, it was necessary to establish which teachers had a misunderstanding of the processes. The Wilcoxon test was not applicable for testing individual teachers for the value of N was too low to obtain any valid results in terms of the calculated T.

Consequently, application of probability theory to the data was undertaken. Under consideration was the question: What was the probability of a teacher making the choices he did by chance alone ? For each lesson (trial) the denominator represented the number of combinations that a teacher could have made, of the choices he made, by chance alone, from the processes. The numerator was the product of the number of combinations possible of right answers according to the criteria in terms of the teachers choices and the number of

TABLE X

THE TEACHERS' PERCEPTIONS OF THE PROCESSES AS COMPARED TO THE CRITERION

Process Pair	Score Criterion	Score Teacher	d	Rank of d	Rank with less Frequent sign
a	5	7	-2	-8.5	
b	11	13	-2	-8.5	
c	3	0	-3	-11.5	
d	4	5	-1	-3.5	
e	5	4	+1	3.5	3.5
f	6	9	-3	-11.5	
g	12	12	0		
h	3	4	-1	-3.5	
i	1	0	1	3.5	3.5
j	2	2	0		
k	5	4	1	3.5	3.5
l	0	2	-2	-8.5	
m	0	0	0		
n	0	0	0		
o	0	1	-1	-3.5	
p	0	2	-2	-8.5	
q	0	0	0		
					T = 10.5, N = 12

Critical value: T (.01) = 7
T (.05) = 14

combinations of error in terms of processes not utilized The summation of the numerators and denominators of the three trials and the ratio obtained provided the probability of the choices being made by chance alone for the three observations. The basis for the detailed calculations is presented in appendix D. To illustrate the procedure used to obtain the probablilty, teacher A is considered. From Table VIII we note that in lesson one he marked off 5 processes, the criterion consisted of 5 processes, with agreement in 3; in lesson two the teacher marked off 4 processes, the criterion 4, agreement in 3; and in lesson 3, the teacher marked off 3 processes, the criterion 3, agreement in 2.

Applying the formula (Chapter III)

$$\frac{{}^{n}C_{r} \cdot {}^{n_1}C_{r}}{{}^{n_2}Cr_2}$$

we have:

$$\frac{(5C_3 \cdot 12C_2) + (4C_3 \cdot 13C_1) + (3C_2 \cdot 14C_1)}{(17C_5) + (17C_4) + (17C_3)} = .011$$

TABLE XI

THE TEACHERS SELECTION OF PROCESSES BY CHANCE

TEACHER	PROBABILITY
A	0.011
B	0.216
C	0.128
D	0.0028
E	0.0095

It is now possible to undertake some objective assessment of the teachers reports. The formal observation attempted to assess the interpretation of the processes as held by the teachers and the researchers. If the critical value is set at the .05 level of significance, two teachers, namely B and C are above this level. This might be interpreted as suggesting these two teachers did not interpret, understand and translate the processes in the way perceived by the researchers. This is not saying that the teachers are wrong, but that the "An Inventory of Processes in Scientific Inquiry" has developed a certain meaning for the investigators. If communication is to be established among the teachers and researchers, then all should hold similar interpretations of the processes of science as outlined by this inventory.

As a result of this, the information provided by teachers B and C should be viewed with caution. Certain misunderstandings appear to exist in the interpretations of the processes and as such may be reflected in the reports.

Table XII, Part I and II presents further information from the formal observation. Part I of the Table XII provides an account of the amount of time spent in teaching the different processes in terms of three lessons. Since all teachers taught different lessons, it is difficult to make generalizations. However, it was noted that two sets of two teachers were teaching in the same content area. Even here, each teacher exhibits an individual pattern. The observation did confirm the information shown in Table VII, in that most teachers spent most of their time in teaching the processes in the upper half of the inventory, namely: Identification of the Problem, Background Information, Collection of Data,

TABLE XII (PART I)

PERCENTAGE OF TIME SPENT IN TEACHING FOR PROCESS DURING THE FORMAL OBSERVATION

Process	TEACHERS A	B	C	D	E
Identify and Form. a Problem	8.2	--	--	5.6	1.9
Background Information	8.2	62.9	7.1	4.7	9.8
Predicting	--	--	--	--	--
Hypothesizing	18.9	--	4.0	--	--
Collection of Data	13.5	--	--	5.6	3.9
Procedure	21.6	--	--	40.1	17.6
Observations	21.6	29.0	49.5	30.8	42.2
Organizing of Data	--	6.4	2.0	--	3.9
Represent Data Graphically	--	--	--	--	3.9
Treating Data Mathematically	--	1.6	37.4	--	16.7
Interpreting the data	8.2	--	--	13.1	--
Form Operational Definitions	--	--	--	--	--
Math. Relationships	--	--	--	--	--
Theory Building	--	--	--	--	--
Further Evidence	--	--	--	--	--
New Problems	--	--	--	--	--
Applying the knowledge	--	--	--	--	--
TOTAL	148	124	198	214	204

TABLE XII (PART II)

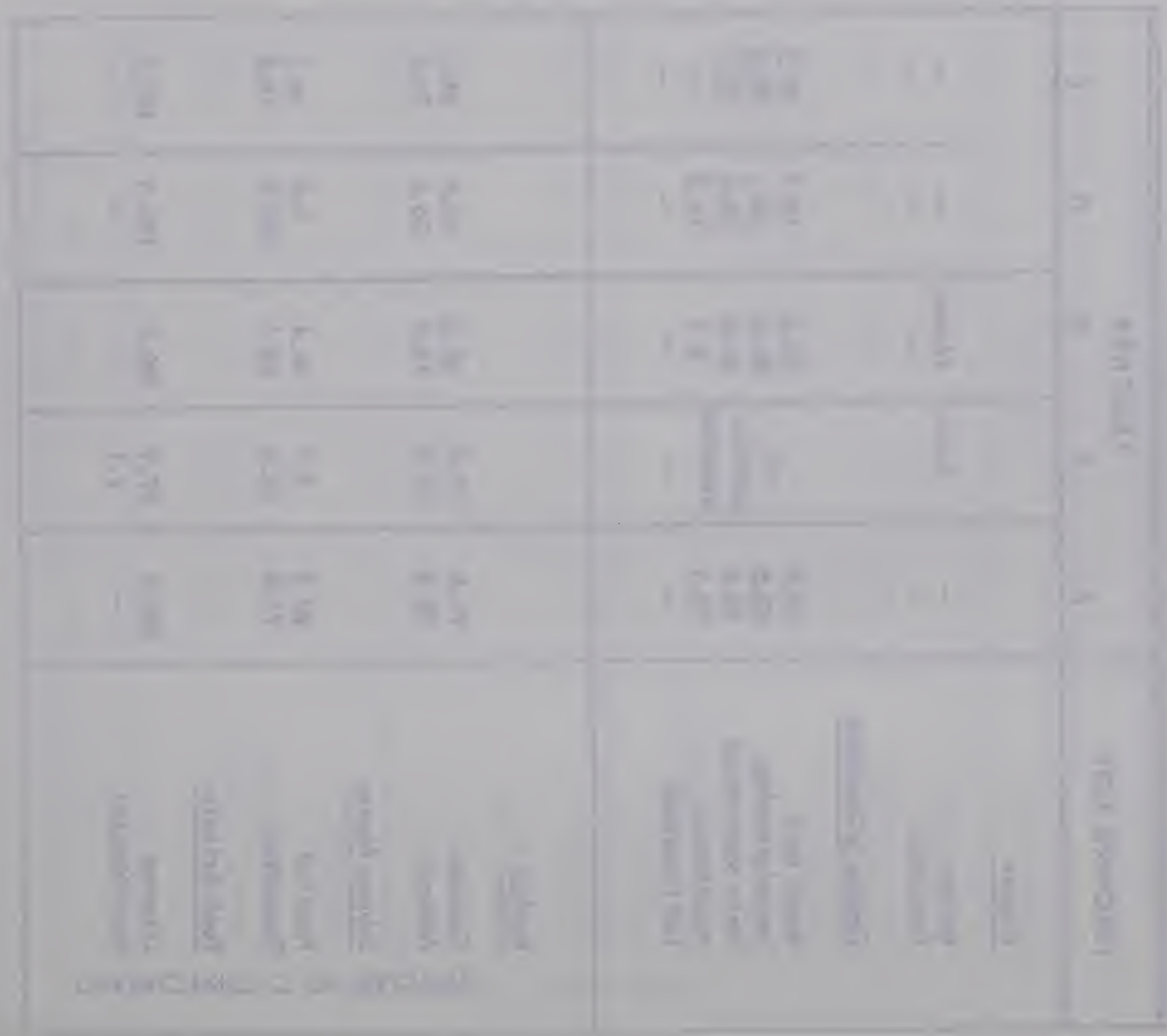
PERCENTAGE OF TIME SPENT IN DIFFERENT TEACHING ACTS IN TEACHING FOR PROCESS DURING THE FORMAL OBSERVATION

TEACHING TECHNIQUES — TEACHING ACTS	TEACHER A	B	C	D	E
Teacher Talks					
Gives directions	2.7	3.2	3.4	3.8	18.6
Introduces	3.9	--	--	--	--
Lectures	2.7	--	--	--	--
Summarizes	1.3	--	2.3	--	2.1
Explains	20.8	--	1.2	--	6.9
Teacher-Student Talk					
Recitation	--	--	--	5.7	--
Request and Ans. Quest.	29.9	--	29.9	5.7	9.3
Discussion	9.3	--	2.3	9.4	1.4
Teacher Does					
Uses A-V	--	--	36.8	--	4.2
Demonstration	3.9	--	--	--	8.4
Helps Indiv. Student*	4.3	44.2	12.6	35.8	16.8
Students Do					
One student-class	--	--	--	--	0.7
Students work indiv.	--	40.0	11.5	--	6.3
Laboratory work*	20.8	12.6	--	39.6	23.8

* The "Helps Individual Student" and "Laboratory Work" are reported separately, but in the classroom they took place simultaneously.

TABLE XII (PART II) Continued

CHARACTERISTICS OF TEACHING — TEACHING ACTS	TEACHER A	B	C	D	E
Purpose					
Review	--	2 min.	16 min.	--	--
Evaluation	--	--	--	--	--
Teacher's Questions					
Recall facts	10.0	no questions presented	35.6	19.1	37.5
See relationships	50.0		35.6	38.1	25.0
Make observations	30.0		20.0	28.6	37.5
Hypothesize	10.0		8.9	14.3	--
Test hypothesis	--	--	--	--	--
Method					
Concrete	70.0	25.0	56.3	63.4	64.7
Abstract	29.9	75.0	43.8	26.6	35.3
Subject Matter					
Practical	22.2	2.7	36.4	0.0	24.2
Theoretical	77.8	97.8	63.6	100.0	75.8
Pupil Activity					
Directed	100.0	97.9	100.0	100.0	100.0
Non-Directed	--	2.1	--	--	--



Procedure, Observations and Interpreting Data. These same processes were generally stressed throughout the period of the study as reported by the teachers.

Table XII, Part II, provides a description of the characteristics of teaching as recorded by the observational instrument. Although it is not possible to generalize the information for the whole school year, certain facets can be noted. Teachers A and E are high on "teacher talks", 31.4% and 27.7% respectively. Teachers A, C, and D provide for considerable teacher - student interaction, 39.7%, 32.1%, and 20.8% respectively. Teacher C, utilizes A-V media to a large extent, 36.8%, although this was part of "teacher talks" and "teacher - student" talk. Four teachers, A, B, D and E had students involved in laboratory situations. With the exception of B, this prevailed throughout the school year. Most teachers do spend considerable time in helping individual students, and this factor may be more important than any other in explaining the reasons for low "teacher talks" and "teacher student talk". The "talk" aspect probably occurred at the individual level, and would not be recorded in terms of the observational instrument.

The teachers questions are those as presented to the total class. Reference should be made to the companion evaluative study for examples of the actual questions. These teacher questions were transcribed from the tapes recorded during the lessons.

Three scales, method, subject matter and pupil activity were used to assess the characteristics of teaching. Method referred to the concreteness or abstractness of a lesson. These are at the opposite ends of a continuum, and refer

to the method of communication used to impart knowledge and understanding. Generally, the five teachers, in terms of method, taught concretely 67% of the time and abstractly 33% of the time. This high value for concrete lessons can be attributed to the use of A-V media and laboratory work which accounts for 30% of the teaching acts. The subject matter as presented was mostly theoretical (approximately 80%) rather than practical (20%). This section considered the subject matter taught. If the lesson consisted of subject matter which is within the experiences of the learner with little or no mention of theory it was considered practical. Otherwise, if theory was presented with no mention of applications, the subject matter was theoretical. Much of the theoretical subject matter is attributed to the content that was being taught when the formal observation was made. This consisted primarily of introductory lessons in embryology and reproductions, and topics in microbiology. In terms of pupil activity, it was nearly 100% directed, that is, the teachers directed the actions of their students. This point was also noted from the teacher reports.

IV. SUMMARY

This chapter attempted to describe, analyze and interpret the process approach teaching as undertaken by five teachers. It was found that the five teachers were each unique in their approaches to teaching for process. It was noted that the laboratory, A-V media, lecture, and discussion were the major instructional modes used by the teachers. In interpreting the "An Inventory of Processes of Scientific Inquiry" there were misconceptions as compared to the

interpretations held by the investigator. It was also sensed that teachers do not really comprehend the complete domain of the scientific enterprise. Consequently, there seems to be some difficulty in translating this to the students. The processes in which the pupils were involved for the major portion of time were indentification and formation of a problem, predictions, hypothesis, background information, design for collection of data, procedure, observations and observing, and interpreting data.

Information from the companion evaluative study should provide further insights on many of the variables discussed in this chapter. It is hoped that when these measures become available many of the factors in this study may be assessed in terms of these measures.

CHAPTER VI

SUMMARY, DISCUSSION, CONCLUSIONS, AND IMPLICATIONS

I. SUMMARY

The present research attempted to develop a methodology in science teaching concerned with the question: "How to teach for the process of science?" The study involved the development of instructional strategies that may be used in the teaching for process in scientific inquiry and the description of process teaching as carried out by five teachers. Specifically, the processes that are involved are the ones outlined in "An Inventory of Processes in Scientific Inquiry".

The process dimension in science teaching has been of concern to science educators for some time. The specific steps of what scientists do have been described as the "scientific method" or "problem solving". Taking the six step formalism developed by Dewey,[1] numerous science educators, including Keeslar,[2] the NSSE,[3] the AAAS,[4] and Welch[5] have refined this series of

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[1] Dewey, Encyclopedia of Educational Research, p. 1193.

[2] Keeslar, "The Elements of Scientific Method," p. 277.

[3] NSSE (1947), p. 29.

[4] Gagné, The Psychological Basis of Science - A Process Approach, p. 4.

[5] Welch, p. 33.

activities and operations performed by scientists in their attempts to understand natural phenomena. The processes used in this study were developed by M.A. Nay and associates, and consisted of five major processes which are further sub-divided into seventeen sub-categories. The major processes are: (I) Initiation, (II) Collection of Data, (III) Processing of Data, (IV) Conceptualization of Data, and (V) Open-endedness. This inventory, entitled "An Inventory of Processes in Scientific Inquiry," was used in the development of the teaching strategies in this study. Approaches to science teaching have also been debated. It has been emphasized that the student should take a more active, as well as responsible position for learning, and it was within this philosophy of education that the strategy of inquiry teaching was established. Schwab became one of the leading proponents of inquiry teaching. Numerous curricula (BSCS, PSSC, IPS, ESCP, and others) were structured to reflect this new philosophy and the processes of science became to be regarded as an integral part of inquiry teaching.

One of the first curricula to incorporate processes of science with the inquiry approach was the AAAS - Science - A Process Approach[6]. This program actively involves the students in inquiry, develops the processes, skills, and presents varied substantive material. At the secondary level, Klopfer and Cooley[7]

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[6] American Association for the Advancement of Science and the Xerox Corporation, Science: A Process Approach (New York: Xerox Corporation, 1968), 1969.

[7] Klopfer and Cooley, Journal of Research in Science Teaching I, (March, 1963).

developed a series of History of Science Cases (HOSC) to convey important ideas about the scientific enterprise, scientists, and methods and aims of science. In order to exhibit science in operation and not to merely talk about science, Schwab[8] developed the Invitations to Inquiry. These invitations pose examples of the process of science and engage the participation of the students in the process. With these major developments in the background the development of further strategies to teach for process was undertaken.

The development of the strategies was based on an instructional model.[9] This model consists of Phase I, the stating of objectives in behavioral terms; Phase II, the development of appropriate learning experiences based on the stated objectives; Phase III, the evaluation of the objectives; and Phase IV, the analysis and revision of the program.

Within this development the process objectives were behaviorally stated in an open-ended form. An outline of basic skills was proposed to compliment these objectives. To provide the appropriate learning experiences, hypothetical approaches were developed and proposed. These were structured on the basis of instructional modes, namely: laboratory, field study, demonstration, History of Science, A-V media, the lecture and discussion, Invitations to Inquiry, simulation and project. To compliment this development and to ascertain what takes place

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[8] Schwab, (1964), pp. 45-51.

[9] Engman, The Science Teacher, pp. 86-87.

in practice, five teachers were invited to participate in the study. These teachers provided reports on the different instructional modes and on the processes taught. The classroom practice was validated by formal observations with the use of a developed observational instrument. The reliability of the observers was established and the reliability of the teachers' reports assessed.

In the development of the methodology, a schema is provided for science teaching as it relates to the scientific enterprise. In each instructional mode, a definition of the mode, a summary of the related research, general aspects of the instructional mode, criteria for use of the mode and the development of a lesson are considered.

The basic strategy in teaching for process in each instructional mode can be considered in terms of the questioning process, the involvement of the pupil, and the method of structuring the lesson. The laboratory provides an avenue through which the processes of science can be actively utilized, particularly with an understanding of the procedures for scientific investigation. When there are limitations in facilities, an aspect of illustration or an element of danger, the demonstration may be used for developing the processes and an inquiry lesson. A-V media can be effectively employed to develop particular processes or, with structuring, many inquiry facets can be incorporated within the limits of these media. When one wants to develop processes in an historical prospective or look at these developments in retrospect, the use of history of science, case history, and original research papers provides an alternative to the more common classroom procedures. Invitations to inquiry make it possible

to engage the student actively in a specific process or processes. To develop investigative procedures for inquiry and the process of science, as well as for many intangible aspects of the scientific enterprise, students may be taught by the project method. Field studies bring the natural environment into the scope of the pupils' learning experiences and provide a place for the student to function in miniature as a professional in the field. For process teaching in which alternative strategies may be experimented with in a realistic and active learning environment, a simulation exercise may be developed. The lecture and the discussion have a place in the instructional strategies in developing many of the aspects of the particular instructional mode.

It was found that the "An Inventory of Processes" could be used in the structuring of lessons and in guiding teaching in the process dimension. The laboratory, A-V media, lecture and discussion, were the instructional modes used most often in the teaching strategy. The processes of science stressed most often were identification and formation of a problem, predictions, hypothesis, background information, design for collection of data, procedure, observations and observing, and interpreting data. Misconceptions in the interpretation of the processes were held by two teachers out of five as identified by the criterion in an observational instrument. These teachers claimed that certain processes were taught, i.e. predictions, hypotheses, etc., but they were not observed by observers in a formal observation.

II. DISCUSSION AND CONCLUSIONS

It would have been most interesting and useful to have available the research evidence on the evaluation aspects of the companion study. Since this study was developmental and descriptive in nature, it is difficult to pass judgement on the different strategies involving the process dimension in the different instructional modes. It is difficult to say whether or not different teaching styles, approaches, and involvement of students had any influence on outcomes in teaching for process. Although the direct evaluation of student performance is excluded, it is possible to present some conjectures based on the findings of this study.

Any change in teaching style usually requires a conscious effort on the part of the teacher to implement a new methodology or procedure. It was found in the teaching for process that a model for instruction provides a basis for such change. The model developed and used in this study provided the necessary structure for instruction and curriculum development. It was necessary to define the behavioral objectives for the syntactical as well as the substantive aspects of science. These objectives became the structure for which strategies were developed. It would follow that in curriculum development appropriate teaching strategies need to be developed for operationalizing and translating stated objectives into behaviors that are desired. This is where weaknesses in curriculum development seem to exist.

Quite apart from what the results of evaluation will show, teachers on the project have expressed the opinion that their teaching procedures improved

when they were consciously required to record their actions. The teachers claimed to be more aware of their capabilities and successes. Also, many felt that what was being taught had to be justified, and as a result science seemed to take on more meaningful aspects for the teachers as well as for the students. This would suggest that teachers probably should interact more with other teachers. Cooperative planning and teaching could provide this interaction and thus provide for a greater awareness and satisfaction in the teaching of science.

Emphasis in the past was often placed on the evaluative aspects relative to the behavioral objectives. In the instructional model utilized in this study, appropriate learning experiences must be developed in an attempt to operationalize the behavioral objectives. The idea of consistency becomes most important, for teaching acts must be based on the behavioral goals. Evaluation, its method and procedure, must be based on both the objectives and the learning situations used to translate these objectives into outcomes. It is noted that this consistency dimension often is not realized in practice, particularly in the development of the appropriate learning experiences. For the teachers in this study the instructional model provided a methodology for process approach teaching and strategies to translate these processes into desired behaviors by means of different instructional modes.

In structuring learning experiences, teachers must provide opportunities for students to link their own lives with science, to identify those generalizations and principles, which have lasting value and to provide for active involvement in the processes of science. This involvement is considered possible within all the

instructional modes outlined. The involvement may be practical or cognitive, but through consistent teaching students will hopefully develop skill in the processes of science.

For the structuring of behavior in the process dimension the 'processes' as outlined in the "An Inventory of Processes in Scientific Inquiry" were used. In developing teaching strategies this inventory provided a composite selection of processes as carried out by scientists. Through its structure the inventory provided a structure for teaching, in that a student goes through a pre-experimental stage (formulating a problem, hypothesizing, and designing an experiment), the experimenting, observing and interpreting stage, and a post-experimental stage, that of open-endedness. It is noted that this inventory may be successfully used with all instructional modes identified and therefore, may serve the purpose of actively involving the student in the scientific enterprise.

It is recognized from this study that the teacher should not only deal with the tactics and strategies of scientific inquiry in his science lessons, but should exhibit the behaviors of a scientist in his own teaching. It is therefore important that the teacher of science have a good knowledge of what science is: its nature and structure. This study showed a misunderstanding of one important dimension of science, that of the processes of science. The specific misunderstanding was in the interpretation of the processes as per "An Inventory of Processes in Scientific Inquiry." This outcome raises the question of how well should philosophy of science be understood before it is practised. A schema for an operational structure in terms of "An Inventory of Processes in Scientific Inquiry"

was provided. The teacher, in effect has the dual responsibility of having a clear understanding of science and scientists, and of being able to translate these behaviors to the pupils through his interactions with them.

From this study it was found that teachers utilize primarily four instructional modes - the laboratory, A–V media, lecture, and discussion. Every mode in this study can lend itself to process approach teaching. Change in itself provides for variety and for motivation, although some modes are probably more applicable in the presentation of certain substantive material. This suggests that teachers should be introduced to the other modes, i.e. History of Science, Invitations to Inquiry, and simulations and explore their various facets as applied to process approach teaching. Workshops in which appropriate learning experiences are developed may recognize the possibilities of the different instructional modes provided in this study.

It should be emphasized that student involvement is to be a prime factor in instruction, for it is believed that this is when learning takes place. Pupils should be involved in the pre- and post- developments of the lessons. In the laboratory situation concerted effort should be made for the pupil to recognize a problem, to formulate his hypothesis, and to design the procedures for the solution to the problem, to "experiment", and finally, to provide some intellectual development. All too often the "experiment" is merely a replication. This would suggest that pupil investigations take on more of an involvement with the pupils' problems. Many of the traditional laboratory exercises could be critically evaluated by the pupil instead of carrying out a "cook book" version of the investigation.

Of the processes as outlined in the "An Inventory of Processes in Scientific Inquiry" any number may be used in the lesson format. The process may be provided for the pupil, e.g. a hypothesis to a problem is stated, or he may be responsible for providing his own hypothesis. It should be remembered that the pupil should be part of the process development.

In summary, four major conclusions are presented:

1. In the development of a curriculum and in the teaching of this curriculum, teachers should have a model or plan for instruction which guides their activities. The plan should provide for growth, balance, and a consciousness of the factors involved.

2. Teachers of science should display behaviors characteristic of scientists within the limitations of their classrooms and be thoroughly familiar with the nature of science and scientists.

3. A variety of instructional procedures can and should be used in presenting the processes of science.

4. The pupils should be actively involved, physically and cognitively in the processes dimension of science. Through structuring the lessons, the process of science should be translated to the pupils in their classroom work.

III. IMPLICATIONS FOR SCIENCE EDUCATION

There are many aspects of science education which may be considered under this heading. If the present trends become more pronounced, the movement toward more autonomy for the science teacher in his classroom and the trend

towards more concern for the individual pupil will necessitate major changes in curriculum and teaching practices. One of these trends may well be the teaching for process in science.

In this study, misconceptions in the interpretation of the processes in the "An Inventory of Processes in Scientific Inquiry" emerged. This aspect alone suggests that the trend toward process approach teaching will require inservice education for the science teacher, with provision for further academic and professional growth. Inservice work will need to stress many of the behavioral objectives that pupils are to attain. In process teaching, teachers will require presentations that involve the processes of science as well as philosophy of science in terms of understanding of the scientific enterprise,of scientists, and of the aims and methods of scientists. At the junior high school level a thorough familiarization of the discipline areas, i.e. Life Science, Earth and Space Science, and Physical Science, in terms of the particular characteristics of each discipline would be necessary.

In their attempts to translate these new objectives, teachers will need leadership, training, and involvement in cooperative ventures in curriculum design and development. Teachers will need to gain competence in the operationalization of the desired objectives, be they the processes dimension or some other. This study revealed that for a major portion of instruction, only four instructional modes were utilized in the process development. This suggests that teachers will need support in developing appropriate learning situations involving varied instructional modes. To obtain this type of instruction and to

provide for the necessary interaction teachers will need considerable amounts of preparatory time and provisions for cooperative planning and development.

For the pupils in science, school facilities and equipment will need to be designed to provide an optimum learning environment. The school library will become a focal point of learning and may need greater expansion. It may be necessary to provide greater and more immediate access, not only for the pupil, but his teacher, to films, filmstrips, records, and important books and periodicals. Within this environment, the pupils' education would not be limited to one or, at most, a few textbooks. As an aid in achieving this aspect, computerized storage and retrieval banks should be considered. Such data banks could be developed to provide instructional aid to teachers and pupils and to assist in individualization of instruction. In summary, attainment of the objectives of process approach teaching will require new orientation for teachers, pupils, and school systems.

IV. FOR FUTURE RESEARCH AND DEVELOPMENT

This study attempted to provide a perspective based on an instructional mode, for curriculum building, instruction, teaching and other facets of the educational enterprise. Within this model the process objectives as set in "An Inventory of Processes in Scientific Inquiry" were translated into behavioral outcomes. By use of different instructional modes, strategies were outlined that might be implemented to effect these behaviors. An attempt at the evaluation of the process dimension is made in a companion study. Future developments and

research can readily centre around this instructional model and might involve some of the following considerations:

(a) Behavioral objectives in the substantive aspects of science have been developed. This study has attempted to outline behavioral objectives in the process dimension. There is a need to outline the behavioral outcomes in the affective dimension of scientists and science, to develop strategies to teach for these, and to develop methods of evaluation in this area.

(b) Instruments to assess growth in the process dimension applicable to the junior high level need to be developed.

(c) This study provided a pattern of process teaching involving the seventh grade and Life Science. It would be informative to investigate how processes can be taught in the two junior high school grades involving Earth Science and Physical Science.

(d) There is a need for a longitudinal approach to the study of process teaching as well as to the study of the affective domain. Such studies may span grades one to twelve and ascertain long term effects of the process approach

(e) "Action" research is necessary to determine the effects of other variables such as the teacher, the classroom organization and climate, the findings from psychology and the resources and facilities available in a school on the teaching-learning situation.

(f) The course outlines for the junior high school sciences consist of a statement of general aspects. Teachers are given the responsibility of

making major decisions in the planning and structuring of the particular discipline to the individual needs of their students. As a result there emerges a need for exploration, development, and evaluation of strategies that would be most successful in (1) teacher involvement in curriculum development, and (2) in the inservice and continuous education of teachers.

(g) It would be of interest to determine which instructional modes are most effective in developing not only the process dimension but also the understanding of scientists and the scientific enterprise. Within this study, student ability, attitude towards science, and other factors could be variables to be investigated.

(h) In teaching for process there are some students who are most eager and enthusiastic and other students who are apathetic towards science and towards education in general. The reasons and factors associated with this characteristic of our student population need to be studied.

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APPENDICES

APPENDIX A

AN INVENTORY OF PROCESSES IN SCIENTIFIC INQUIRY

EXPLANATION OF PROCESSES IN SCIENTIFIC INQUIRY

AN INVENTORY OF PROCESSES IN SCIENTIFIC INQUIRY

(Revised Edition*, 1970, as submitted to Science Education)

THE SPECIFIC PROCESSES

I. Initation

1. Identifying and formulating a problem

(a) speculating about a pheonomenon

(b) identifying variables

(c) noting and making assumptions

(d) delimiting the problem

2. Seeking relevant background information

(a) recalling relevant knowledge and experiences

(b) doing literature research

(c) consulting people

3. Predicting

4. Hypothesizing

5. Design for collection of data through field work and/or experimentation

(a) defining the independent and control variables in operational terms.

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* The Fifth Draft of the "inventory", August 1968 appears in the Doctoral Dissertation by E. Mokosch. Prepared by the Edmonton Junior High Science Project; the group consisted of M.A. Nay, R. Melynchuk, E. Mokosch, D. Powley, R. Roberts, D. Thomas, H. Visscher, D. Whitlock.

(b) defining the procedure and sequencing the steps

(c) identifying needed equipment, materials and techniques.

(d) indicating saftey precautions

(e) devising the method for recording data

II. COLLECTION OF DATA

6. Procedure

(a) collecting, constructing, and setting up the apparatus or equipment.

(b) doing field work and/or performing the experiment

(c) identifying the limitations of the design (as a result of failures, blind alleys, etc.) and modifying the procedure (often by trial-and-error).

(c) repeating the experiment (for reproducibility, to overcome limitations of initial design, etc.)

(e) recording data (describing, tabulating, diagramming, photographing, etc.)

7. Observing and observations

(a) obtaining qualitative data (using senses, etc.)

(b) obtaining semi-quantitative and quantitative data (measuring, reading scales, calibrating, counting objects, or events, estimating, approximating, etc.)

(c) gathering specimens

(d) obtaining graphical data (charts, photographs, films, etc.)

(e) noting unexpected or accidental occurrences (serendipity)

(f) noting the precision and accuracy of data

(g) judging the reliability and validity of data

III. Processing of Data

8. Organizing the Data

(a) ordering to identify regularities

(b) classifying

(c) comparing

9. Representing the data graphically

(a) drawing graphs, charts, maps, diagrams, etc.

(b) interpolating, extrapolating, etc.

10. Treating the data mathematically

(a) computing (calculating)

(b) using statistics

(c) determining the uncertainty in the results

IV. Conceptualization of Data

11. Interpreting the data

(a) suggesting an explanation for a set of data

(b) deriving an inference or generalization from a set of data

(c) assessing validity of initial assumptions, predictions and

hypotheses

12. Formulating operational definitions

    (a) verbal

    (b) mathematical

13. Expressing data in the form of a mathematical relationship

14. Incorporating the new discovery into the existing theory (developing a "mental model")

V. Open-endedness

15. Seeking further evidence to

    (a) increase the level of confidence in the explanation or generalization

    (b) test the range or applicability of the explanation or generalization

16. Identifying new problems for investigation because of

    (a) the need to study the effect of a new variable

    (b) anomalous or unexpected observations

    (c) incompleteness ("gaps") and inconsistence in the theory

17. Applying the discovered knowledge

EXPLANATION OF THE PROCESSES IN SCIENTIFIC INQUIRY

(Based on the Fifth Draft of the Inventory)

A careful look at the Inventory will show that scientists work mainly with their brains rather than their hands. Yet the "test of Truth" is derived from the observation (data) obtained from field work or experiments in the laboratory. Therefore, scientific activity requires an appropriate combination of thought and physical work.

It should be pointed out that although the processes are numbered from one to seventeen, no rigid order is implied. Scientific investigations do not proceed always in an orderly manner from step one to seventeen. Furthermore, in any given investigation it may not be necessary to include all the steps. Finally, two or more processes often overlap or are "telescoped" into a single operation.

I. PREPARATION

This major division includes activities encountered before the collection of data begins.

1. Problem

There are many things and events in the universe about which every person wonders and speculates. Thus, accidentally or deliberately we are continually identifying problems, any one of which could be investigated to obtain an answer or solution. For instance a problem may arise from observing a phenomenon (e.g., a rainbow), noting discrepancies in nature (e.g., a liquid flowing upward), or merely from curiosity. The problem may be stated in the form of a question:

Example: What is a rainbow?

or as an infinitive phrase:

Example: To determine how a liquid can flow upward.

The investigation can be more fruitful if the problem is clearly defined or formulated. We need to identify those variables which will suggest the kind of data to collect through field work and/or experimentation in the laboratory, and how to collect it. Variables are factors, conditions or properties which operate within or influence the phenomenon under investigation.

Example of variables: weight, temperature, distances, water supply, cosmic radiation, animal population density, etc.

Often to be able to find an answer to a problem, we have to make assumptions.

Examples of assumptions: certain variables have no effect on the phenomenon, reliable data can be obtained, etc.

Finally, the problem may have to be delimited. Otherwise too big an area may have to be covered, making the experiment too difficult to perform, or the data too unreliable or confusing to be of much value. This immediately places a limit on the knowledge we can obtain about the problem. However, what we do find out will probably be more reliable and valid.

2. Background Information

Before any problem can be investigated or solved, or perhaps even before it can clearly be defined, some information is needed. This consists of background theory, knowledge of what other scientists have done on the same (or similar) problem, ideas on the apparatus and techniques to use, precautions, etc. The investigator may already have some useful knowledge for solving the problem. Usually, he can get a great amount of information through literature research; that is, by reading appropriate books, papers, articles, etc. Listening to speeches and discussing the problem with other people is another method of obtaining the necessary background. (In school, the people consulted will be mainly the science teachers and classmates, although occasionally it might be possible to consult a scientist who is an expert in the area being investigated.)

3. Predictions

Predictions are based on the fact that the universe operates in a regular manner, and that we expect known phenomena to occur always in the same way.

Examples: the movements of the moon, changes in season, effect of gravity, flow of heat, boiling, etc.

This behavior of natures allows us to make predictions based on past experience. Whether a prediction is right or wrong depends on the probability of something happening in the expected way. For instance, our prediction that the sun will rise tomorrow morning is almost certain to be correct, since the probability of the sun rising is near certainty. The prediction of "heads" in coin-tossing will be right only fifty per cent of the time. Predictions for rain in a specified place at a definite time will probably be wrong most of the time,

because the probability of this happening is very low.

A prediction may or may not suggest specific observations to make or procedures to follow to test the prediction.

4. Hypothesis

A hypothesis is a possible or tentative explanation for a phenomenon. This may be anything from a conjecture, guess or assumption to an explanation which is highly probable in the light of known observations or facts.

Examples: The hypothesis that there are other planets in the universe with thinking beings inhabiting them is not much more than a (statistical) guess. On the other hand, the existence of Pluto and Neptune was hypothesized to account for some anomalous astronomical behavior.

It is usual to try to test (prove or disprove) the validity or truth of a hypothesis by collecting more data. To do this a working hypothesis might be stated to guide the investigation.

Example:

Hypothesis: Birds migrate south in the fall because of the decreasing length of daylight.

This suggests an experiment in which two variables may be studied for birds in a windowless case: length of artificial daylight and the direction of flight.

The following example illustrates the distinction among problem, prediction and hypothesis.

Situation: If a glass of water is placed on a paper towel which is then whisked out from underneath . . .

Problem: Will the glass of water remain upright?

Prediction: Probably not since experience with imbalances of forces suggests that in this case the glass will move and probably tip over.

Hypothesis: Involved is not only an imbalance of forces, but also inertia. Consequently, if the towel is whisked out from under the glass with a quick, jerky motion and the towel is dry, the effect of the inertia will be dominant.

5. Design for Collection of Data

A solution or explanation for a problem may be stated first as a hypothesis, but the truth or validity thereof can be established only on the basis of the right observations or data. This data may come entirely from experiments performed in the laboratory (as in chemistry or physics), or from field work which often is combined with laboratory activity (as in geology and biology).

The value of planning the method or procedure for collecting the data is obvious. First the researcher has to deal with the variables. It is common practice to study only some of the variables (called independent variables) while keeping all the others under control ("held constant").

Example: Referring to the above experiment with a glass of water on a towel, if the variable being studied is the speed of removing the towel, then the controlled variables are the amount of water in the glass (same amount in all the experiments), wetness of towel (keep it dry), roughness of table, etc. After the effect of changing one variable has been studied, it can then be controlled in turn while the effect of changing some other variable is studied (e.g., varying the amount of water in the glass, from zero to full). This aspect is referred to again under "open-endedness" in Process 16 (b).

Having made a decision about the variables, the scientist then develops a method of collecting the data including the apparatus needed, the steps to be followed, the precautions to be taken, and manner in which the data is to be recorded (e.g., narrative and tables in a notebook, charts from electronic measuring instruments, photographs, specimens, etc.).

II. COLLECTION OF DATA

This general category includes the activities associated with the actual collection of data, in the field and/or laboratory. (In science teaching this phase is commonly referred to as "experimentation" or "laboratory work". This designation is incomplete since in many sciences much data is obtained in activities which do no resemble experiments, and in locations outside of a room called a "laboratory".)

6. Procedure

The scientist starts his data collection by following the design. He may be fortunate in collecting sufficient reliable and reproducible data without undue deviation from the design. However, it is more probable that he will encounter difficulties of varying gravity. He may have trouble getting or building the required equipment, and setting it up. The recording system may

not be sufficiently sensitive or stable. He may have to learn by trial-and-error how to perform the experiment properly. He performs the experiments, but the results do not make any sense (a "blind alley"), or give him only limited information. He tries a procedure repeatedly but without success (a "dead-end"). In the field he may search different areas for specimens but may find few or none. These and countless other kinds of difficulties may result in failure. If he accepts the failure as temporary, he may do more reading, thinking, and designing - and then try again. However, if he cannot see a way out, he will drop the problem under investigation and go on to another one.

All of the above obstacles (some foreseen and others not) to success are part of the limitation of the design. Throughout the entire operation the scientist records for future reference, everything he does, whether successful or not.

7. Observation

The observations made constitute the data of research, and many of them become part of the theory as facts.

The scientist develops keen power of observation. He tries to be systematic so that nothing goes un-noticed in his investigation. As a result he is prepared for the accidental or unexpected events when they occur (many of which give rise to more important problems than the original one). The data is of various kinds and appears in various forms as indicated in process 7 (a), (b), (c), and (d), of the inventory.

The scientist also takes into account the precision and accuracy of his results (including possible errors, significant figures, etc.). The precision may be high in that every time he does a given experiment he gets the same result (within experimental error). However, the result itself may be inaccurate because the apparatus was not working properly, there were impurities in the chemicals, etc.

Analogy: In target practice, the precision is high if the bullet holes are all close together. For the accuracy to be high, these holes should be near or at the bull's eye.

III. PROCESSING OF DATA

This general category deals with what happens to the data after collection, but before interpretation. Putting the data in some more systematic form may reveal generalizations more readily, help to identify mathematical relationships between variables, etc. Actually the strict separation between data processing and interpretation is a little artificial, as some conceptualization

usually has already taken place when the data is being processed.

8. Organization of Data

To make data more meaningful, it often has to be rearranged, compared ordered or classified. Sometimes this step is performed before the actual performance of an experiment, as is the case when suitable variables are tabulated before making the actual observations. Usually, however, data is recorded in some "rough" fashion and has to be organized in some more compact and meaningful way.

9. Graphical Representation

This process involves systematizing the data graphically, in order to obtain "hidden" information and thus facilitate interpretation and make it more complete. Such "hidden" information is found in extra-polations and interpolations, intercepts, contours, cross-sections, and isopleths (e.g., isobars, isotherms, isoclines, etc.). These graphical representations often make possible predictions (e.g., rainfall from weather maps, oil deposits from geological cross-sections, etc.).

10. Mathematical Treatment

Quantitative data is often processed mathematically for a number of reasons. One is to make it more meaningful by deriving constants from multiplication or division of data, rates of change, slopes and areas from graphs; determining statistical distributions; etc. Another is to help define the "level of confidence" that can be placed in the observations through such operations as averaging, finding per cent errors, etc. In the mathematical treatment, often the chance effects of uncontrolled or unidentified variables becomes evident.

IV. CONCEPTUALIZATION OF DATA

This general category deals with the process of bringing conceptual understanding and order into the facts (observations or data). Here we are concerned with the PRODUCT or CONTENT of a scientific discipline. The relevant information identified under the process of "background knowledge" is vital for this stage of scientific inquiry.

11. Interpretation of Data

(In science teaching, this process has been seen mainly as one of "drawing a conclusion." The word "conclusion" is misleading since, although

a given investigation may be concluded, it gives rise to a host of new problems for investigation.)

A scientific investigation is undertaken to find an explanation or solution to a problem. In due course a body of observations is obtained from which generalizations (laws, principles) are deduced, and/or for which appropriate explanations are devised. Of primary concern are composition and structure (e.g., living tissue), function, relationships (e.g., pressure versus temperature for gases), and cause-and-effect (e.g., heating water). Interpretation involves inference since often the mind must go "beyond the facts" for an appropriate generalization or explanation.

It is essential to note that it is not easy to answer even a simple problem unambiguously by experiment or field work. Therefore, vigilance must be exercised in interpreting data; that is, no more should be inferred than is justified. There is always a limit on the new knowledge that can be obtained in any single investigation.

At this stage the validity of initial assumptions and hypotheses must be assessed. New problems have arisen in the course of the investigation (open-endedness). If these stem from errors and weaknesses in the experimental design, then the initial hypotheses and assumptions may be reformulated in preparation for a repeat of the investigation.

12. Operational Definitions

Formulating operational definitions is only indirectly a process in scientific inquiry; it is primarily an aspect of the language of science. Scientists find it useful and convenient to use a word or a brief phrase to identify the operation of an object or an event in nature. Therefore, an operational definition encompasses the minimum description or minimum action needed to identify an object or event. Often more than one definition is possible, the choice depending on suitability.

Example: Define the word "boiling".

1. Boiling is the event in which bubbles are formed continually throughout a heated liquid, and rise to the surface when they "break".

2. Boiling is the event in which the maximum constant temperature (as measured with a thermometer) is obtained for a heated liquid.

13. Mathematical Relationships

Usually this process is part of the interpretation of data. One reason

why it is shown separately is that considerable importance is attached to quantitative generalizations in science. An important outcome is that manipulation of a mathematical relationship may often provide information which was not apparent from the data. Another important reason is that scientific relationships can be derived entirely mathematically (e.g., Einstein's equation relating matter and energy, $E = mc^2$). In both situations new problems may be identified for investigation, to prove or disprove the ideas deduced mathematically.

14. Development of a Theory

Whereas interpretation is a process concerned with the data from the investigation, theory building involves fitting and integrating the new knowledge into the theory already existing or revising this theory to accommodate both the new and old facts. Facts, laws, principles, concepts, conceptual schemes, hypotheses, etc. are the "bones and flesh" of a theory. Considerable insight and intuition (involving going "beyond the facts") are called for to bring about a consistent integration of these elements of a theory. Since much of this theory goes beyond what can be observed directly (e.g., atoms, molecules, genes, etc.) and exists primarily in the scientist's mind, the term "mental model" building has become popular in science (and science teaching).

It is at this stage of inquiry that the provisional (tentative) and self-correcting (revisionary) nature of scientific knowledge is most apparent. For instance, the new findings may show some of the old principles to be erroneous or obsolete and in need of revision. Or the new data may help to settle which of two existing theories is more plausible. In any event, a host of new problems stem from gaps, inadequacies, conflicts, and inconsistenties in the theory, and new assumptions and hypotheses may be formulated as a prelude to new investigations.

V. OPEN-ENDEDNESS

Science is always an unfinished business. One often hears that each investigation raises many more questions than it answers. This aspect of the scientific enterprise is often referred to as "open-endedness." In this inventory, the open-endedness is seen in terms of the need for further support for a generalization or explanation, the application of this generalization or explanation in explaining new phenomena (some of which have been long observed but not understood), and the pursuit of new problems related to the one being investigated.

15. Further Evidence

Obviously, the level of confidence in a generalization or explanation

will be low if errors or weaknesses in some stage of the investigation have been spotted. Those which appeared early might be remedied at the data-collecting stage, while those appearing later may require the investigation to be redone. Often there is a "pilot" stage in an investigation for the purpose of testing the design for data collection, and revealing some of the difficulties and pitfalls.

In some cases it is useful to repeat an investigation (in the same or a modified form) to accumulate more evidence for interpretation. For example, the average of several temperatures of boiling water is more reliable than a single reading. Or it may be desirable to determine a more accurate boiling point using a more sensitive thermometer and better experimental technique.

When a scientist obtains a generalization or explanation for one substance, he may want to know how other sustances behave when the same variables are studied. Thus he increases the range of application of the generalization. For example, when he studies the effect of heat on several different liquids, he finds that all of them can be made to boil.

16. New Problems for Investigation

As was already mentioned under Process 14, "gaps", inconsistencies, discrepancies, or weaknesses in the theory point the way to new investigations.

One characteristic of new problems is the inclusion for the study of at least one new variable. A standard way in which this is done in research is to make one of the control variables in a previous investigation an independent variable (see example under Process 5, above).

Anomalous behavior or unexpected observations usually are the result of some variables not being recognized initially (hence no provision being made to control them). Often these give rise to investigations which are much more important that the one in which they appeared. For example, it is found that all liquids boil, but the boiling points differ. In addition, the boiling temperatures will varying with altitude. Fleming's discovery of the effect of penicillin is a more dramatic example of the importance of "accidental" or "chance" discovery in the development of science.

17. Application

The scientific knowledge gained from an investigation may be applied in a number of ways. Perhaps the simplest is its use in solving some related problem arising out of the open-endedness of the investigation. Often knowledge gained in one area may help increase the knowledge and understanding in another. Such applications may vary in magnitude, ranging from explanations of simple concrete

phenomena to providing the basis for entire scientific fields (e.g., physics in biophysics, chemistry in geochemistry). Another important application of scientific knowledge is in technology (applied science) through which man gains control over parts of his environment and improves his own well-being.

APPENDIX B

TEACHER REPORT FORMATS

REPORT I I: REPORT OF INSTRUCTIONAL MODE, PROCESSESS AND OPERATIONAL ASPECTS

School _____ Date _____

Concepts/Content

INSTRUCTIONAL MODE	PROCESS(ES) (Behavioral Objective)	OPERATIONAL ASPECTS (a) How did the operational aspect relate to the instructional mode? i.e. in what ways is this instructional mode useful in teaching this/these process(es)? (b) How were students involved? i.e. Getting at process(es) in this instructional mode?

How were basic skills taught?

EVALUATION: How successful were you with what took place operationally?

REPORT/: Teaching for Process in Scientific Inquiry

School/Name _____ Date _____ Class Time _____

LESSON (Concepts/Content)

(General description of situation)

INQUIRY MODES		Time (Fraction)
Laboratory	_____	_____
Field Trip	_____	_____
Invitations to Inquiry	_____	_____
Lecture	_____	_____
Case Study	_____	_____
Simulation	_____	_____
Demonstration	_____	_____
A.V.	_____	_____
Discussion	_____	_____
Project	_____	_____
Other (state)	_____	_____
_____		
_____		

SCIENCE PROCESSES
(Behavior Objectives) (Check off)

PREPARATION

1. Ident. & Form. of problem _____
2. Background Inf. _____
3. Predictions _____
4. Hypothesis _____
5. Design _____

EXPERIMENTATION

6. Procedure _____
7. Observation _____

PROCESSING OF DATA

8. Organizing data _____
9. Graphing _____
10. Mathematical treatment _____

CONCEPTUALIZATION OF DATA

11. Operational Definitions _____
12. Inference _____
13. Mathematical Relationship _____
14. Mental Models _____

OPEN ENDEDNESS

15. Further Evidence _____
16. New Problems _____
17. Application _____

INSTRUCTIONAL PROCEDURE
(Teaching for Process)

(a) How was "process" incorporated into the lesson, i.e., made operational?
- what did you as a teacher do?
- how was the class motivated?
- how were associated and basic skills taught?
- what materials and methods were used?
- what were the problems and your solutions?
- be specific, i.e., questions asked, presentations to pupils, etc. Indicate time (min.)

(b) Evaluate the effectiveness of what was done and indicate what modifications you would make.

SPECIFIC INFORMATION

1. How were the behavioral objectives made operational? How did the operational aspect relate to the Instructional Mode?

2. How were the students involved in the teaching for process?

3. How was the class motivated?

4. What types of questions and questioning techniques were employed?

5. What were the dynamics of the discussion?

6. What group dynamics were employed?

7. How was discipline and general class management handled?

RELATED FACTORS

1. How structured or unstructured was the lesson?

   unstructured 0 1 2 3 4 5 structured

2. What provision was made for:

   (a) Individualized study: None 0 1 2 3 4 5 Much

   (b) Independent study: None 0 1 2 3 4 5 Much

3. How were different ability levels handled?

4. Facilities (requirements and use)

5. What instructional material was devised? How was it used? (Provide samples)

6. How were communication and reading skills developed?

OTHER COMMENTS

APPENDIX C

THE OBSERVATIONAL INSTRUMENT

THE OBSERVATIONAL INSTRUMENT

Part I: The Processes

Date _____ Class _____ Teacher _____

Time (2 min. interval)	Sepcific Behaviors	Major Process	
	(a) Speculating about a phenomenon (b) identifying variables (c) noting and making assumptions (d) delimiting the problem	Identifying a problem	1
	(a) recalling knowledge and experiences (b) doing literature research (c) consulting people	Background Information	2
	Predicting		3
	Hypothesizing		4
	(a) defining independent and control variables (b) defining procedure and sequence step (c) indent. equip, materials and tech. (d) indicating safety precautions (e) devising method recording data	Design	5
	(a) construct. & setting up apparatus (b) performing the experiment (c) ident. limitations of design (d) repeating the experiment (e) recording data	Procedure	6
	(a) obtaining qualitative data (b) obtaining quantitative data (c) gathering specimens (d) obtaining graphical data (e) serendipity (f) noting precision and accuracy data (g) judging reliability & validity	Observing and Observations	7
	(a) ordering to identify regularities (b) classifying (c) comparing	Organizing Data	8
	(a) drawing graphs, charts, maps (b) interpolating and extrapolating	Representing Data Graphically	9
	(a) computing (b) using statistics (c) determining uncertainty in the results	Treating data Mathematically	10
	(a) suggesting an explanation for data (b) deriving an inference or generalization (c) assessing validity	Interpreting	11
	(a) verbal operational definitions (b) mathematical op. definitions	Operational Definitions	12

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Part I: The Processes

Time (2 min. intervals)	Specific Behaviors	Major Process
	Mathematical relationship	
	Incorporating into Theory	
	(a) increase level of confidence (b) test range of application	Seeking Further Evidence
	(a) effect of a new variable (b) unexpected observations (c) incompleteness in theory	New Problems
	Applying the discovered knowledge	
17	16	15 14 13

Date _____ Class _____ Teacher _____

THE OBSERVATIONAL INSTRUMENT (Continued)

Part II: The Characteristics of the Science Teacher

Time Interval		
Gives Direction Introduces Lectures Summarizes Explains	Teacher Talks	TEACHING TECHNIQUES
Recitation Request & ans. quest. Discussion	Teacher Student Talk	
Uses A-V aids Demonstration Helps individual student	Teacher Does	
One student - class Students work indv. Laboratory work	Students Do	
Review Evaluation	PURPOSE	
Recall facts See relationships Make observations Hypothesize Test hypothesis	TEACHER'S QUESTIONS	
Concrete Abstract	Method	CHARACTERISTICS
Practical Theoretical	Subject Matter	
Directed Non-Directed	Pupil Activity	

INTERPRETATIONS USED IN THE OBSERVATIONAL INSTRUMENT

Part I: The Processes - Interpret these behaviors as outlined by the specific behaviors. Refer to an "Explanation of the Processes in Scientific Inquiry". (Appendix A)

Part II: The Characteristics of the Science Teaching
- Interpret these as outlined by Fischler and Zimmer.

TEACHING TECHNIQUES

A. In the following, the teacher does all of the talking.

1. Gives directions: The teachers gives specific directions for proceeding with an assignment or for performing an exercise or experiment.

2. Introduction: The Teacher introduces the lesson, or part of a lesson by indicating the purpose or objective or by telling the students what to look for (as in a demonstration or laboratory exercise.)

3. Lecture: The teacher talks to the class for an extended period of time. He may ask an incidental question while lecturing, but if several questions are asked, it would indicate that the category to be checked would be under section "B" of this summary.

4. Summarizes: The teacher recapitulates the main points of the lesson, a part of the lesson or the answers to a series of related questions.

5. Explains: The teacher tries to make clear a meaning or concept which is not understood by the students. In this category the teacher is explaining because he has determined that the students do not understand. It should be clear to the observer that the teacher is explaining for this reason.

B. In the following both the teacher and students talk.

1. Recitation: The teacher asks questions and solicits answers from the students. This category should only be recorded when there is a continuous question and answer period between the teacher and students. Usually the teacher will call on a student as each question is asked. In general, the questions will be more of the recall type than of other types.

2. Requests Questions: The teacher requests and answers questions asked by students. Unless the teacher asks for questions, this category should not be recorded.

3. Discussion: Discussion involves a give and take between the teacher and students. The students ask questions as well as answer them. Students contribute information voluntarily. In most cases, however, the teacher will take the lead in asking questions to start the discussion and keep it going. Sometimes it may be difficult to decide between a discussion and a recitation. One criterion might be that in a discussion the teacher lets more than one student contribute to the answer of a question. In general the questions in a discussion will be more of the relationship or hypothesis type than recall as is found in a recitation.

C. In the following the teacher does something as well as talk.

1. Uses A-V Aids: The teacher makes use of one or more of the various audio-visual aids. In a few cases, the use of the A-V aid will be the dominant technique; for example, the use of a motion picture or filmstrip.

2. Demonstration: The teacher shows or illustrates a process, principle or how something works or functions. Usually objects and/or equipment are used in a demonstration but not necessarily. The criteria for a demonstration is action, the demonstrator does something. Just showing an object, such as a model, does not constitute a demonstration.

3. Helps Individual Students: The teacher helps students individually with their work. This can only be done when students are working individually. Therefore, this item will only be checked when either "students work individually" or "laboratory" is also checked. Many times it will be necessary to distinguish between this category and "students work individually." The observer must decide if the teacher has planned for the students to work individually, so that he can help individual students (in which case this category should be recorded), or if the teacher's help is incidental to the individual student's work.

D. In the following, the students are doing something other than answering questions and discussing with the teacher. What they are doing should be indicated by use of the code in the box and by comments.

1. One Student or Small Group to Class: An individual student or small group performs before the class. He may be giving an oral report, working on a problem on the board, reading from a book, etc.

2. Individual or Group Work: All of the students work either individually or in small groups. This does not mean taking notes when the teacher is talking or another student is giving a report. This is other than laboratory work also.
3. Laboratory Work: All students are doing laboratory type work. This means doing some sort of exercise or experiment usually using materials and equipment.

E. Purpose of the lesson: Sometimes the teacher will use one of the aforementioned teaching techniques for the purpose of review or teaching evaluation.
1. Review: The teacher makes a deliberate attempt to go over and "review" material that has been studied (it may be necessary to determine from the teacher if a particular lesson is review). Questions on material studied for homework should not be considered review for this purpose.
2. Evaluation: The teacher makes a deliberate attempt to determine the learning that has taken place. Usually this will be by means of a test, or quiz, and a grade is recorded by the teacher.

TEACHER'S QUESTIONS

1. Recall Facts: A question requiring the student to do no more than simple recall of facts or bits of information.
2. See Relationships: A question requiring the student to see and understand relationships between ideas or facts in order to explain, generalize, pick out examples, etc., in answering the question. This will usually, if not always, require the student to recall facts, but requires also that he relate the facts in some way.
3. Take Observations: A question requiring the student to make an observation in order to answer. The type of question will usually be directed toward a demonstration of laboratory work. The word "observation" is used in the scientific sense of using one's senses (sight, smell, hearing , touch, and taste) to determine the nature of something. This does not mean remembering an observation made previously outside the classroom. Sometimes a question will be directed to an observation but require seeing relationships or making an hypothesis.
4. Hypothesize:A question requiring the student to reason out or even to guess the answer, based on past knowledge or experience.
5. Test Hypothesis: A question requiring the student to validate or suggest ways to validate an answer, fact or hypothesis.

CHARACTERISTICS OF TEACHING

1. Concrete ↔ Abstract: At the abstract end of this continuum, the instructor uses verbal and written symbols, while at the other end the real object is used. In between will be various substitutes such as models, pictures, diagrams, mock-ups, etc. This continuum refers to the method of communication which the teacher used to impart knowledge and understanding. In practice, the abstract end will be checked only if the teacher and/or students talk and/or write; the concrete end, only if the real object is used. Use of any of the various A-V aids will place the check in the middle.

2. Practical ↔ Theoretical: This is the continuum which, at one extreme, makes use of applications or principles to subject matter which is within the experience of the learner and which is used by him; at the other extreme, theory is presented with no application to the learner's experience. This continuum has to do with the subject matter taught. It there is little or no mention of theory or scientific principles, the lesson will be considered practical; if no mention is made of practical applications, it will be theoretical.

3. Directed ↔ Non-directed: This continuum applies only to student activities. By this is meant the extent to which the teacher actively directs the students in their actions. At one extreme, the teacher gives very explicit directions, frequently in writing; at the other, the student is left on his own.

THE TEACHER CHECK LIST

Teacher _____ Class _____ Date _____

PROCESSES OF SCIENCE

PREPARATION

1. Ident. & Form. of Problem _____
2. Background Inf. _____
3. Predictions _____
4. Hypotheses _____
5. Design _____

EXPERIMENTATION

6. Procedure _____
7. Observation

PROCESSING OF DATA

8. Organizing Data _____
9. Graphing _____
10. Mathematical Treatment _____

CONCEPTUALIZATION OF DATA

11. Operational Definitions _____
12. Inference _____
13. Mathematical Relationship _____
14. Mental Models _____

OPEN ENDEDNESS

15. Further Evidence _____
16. New Problems _____
17. Application _____

APPENDIX D

THE PROBABILITY CALCULATIONS

THE PROBABILITY CALCULATIONS OF THE TEACHERS SELECTION OF PROCESSES BY CHANCE

Teacher A

$$\frac{(5C_3 \cdot 12C_2)}{(17C_5)} + \frac{(4C_3 \cdot 13C_1)}{(17C_4)} + \frac{(3C_2 \cdot 14C_1)}{(17C_3)}$$

Teacher B

$$\frac{(1C_1 \cdot 16C_1)}{(17C_2)} + \frac{(2C_1 \cdot 15C_1)}{(17C_2)} + \frac{(3C_2 \cdot 14C_1)}{(17C_2)}$$

Teacher C

$$\frac{(4C_4 \cdot 13C_3)}{(17C_7)} + \frac{(2C_2 \cdot 15C_7)}{(17C_9)} + \frac{(3C_3 \cdot 14C_5)}{(17C_8)}$$

Teacher D

$$\frac{(3C_3 \cdot 14C_2)}{(17C_3)} + \frac{(4C_4 \cdot 13C_1)}{(17C_5)} + \frac{(4C_3 \cdot 13C_2)}{(17C_5)}$$

Teacher E

$$\frac{(5C_5 \cdot 12C_0)}{(17C_5)} + \frac{(4C_3 \cdot 13C_1)}{(17C_4)} + \frac{(5C_4 \cdot 12C_1)}{(17C_4)}$$

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